Fisheries and Oceans Canada | Pêches et Océans Canada
Science | Sciences

Canadian Science Advisory Secretariat (CSAS)

Research Document 2013/034

Maritimes Region

Scotian Shelf Shrimp 2012-2013

D. Hardie[1], M. Covey[1], and M. King[2]

[1]Population Ecology Division
Fisheries and Oceans Canada
Bedford Institute of Oceanography
P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2

[2]2261 Fox Island
RR #1 Canso
Guysborough County, Nova Scotia B0H 1H0

January 2014

Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

© Her Majesty the Queen in Right of Canada, 2014
ISSN 1919-5044

Correct citation for this publication:

Hardie, D., Covey, M., and King, M. 2014. Scotian Shelf Shrimp 2012-2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/034. v + 44 p.

Aussi disponible en français :

Hardie, D., Covey, M., et King, M. 2014. Crevette du plateau néo-écossais (2012-2013). Secr. can. de consult. sci. du MPO. Doc. de rech. 2013/034. v + 48 p.

TABLE OF CONTENTS

Abstract iv
Résumé v
Introduction 1
Methods And Materials 3
- Traffic Light Indicators 3
- Data Sources 4
- Traffic Light Summary 6
- Bycatch 6

Results and Discussion 7
- Precautionary Approach 7
- Abundance 7
- Production 9
- Fishing Impacts 12
- Ecosystem 14
- Traffic Light Summary 18
- Sources Of Uncertainty 19

Acknowledgements 20
References 20
Tables 22
Figures 29

ABSTRACT

The Fisheries and Oceans Canada-industry survey stratified mean decreased for the third consecutive year, falling 8% from a total biomass estimate of 30,510 mt in 2011 to 28,028 +/- 4560 mt in 2012. Although spawning stock biomass also decreased by 12%, it remains in the Healthy Zone for this stock. A precautionary 9% reduction in the 2012 total allowable catch helped to ensure that female exploitation index (19%) did not exceed the removal reference point for this stock (20%). Overall, the survey and commercial catch per unit effort indices suggest that the stock is moderately abundant, which is consistent with the prediction that the 2007-2008 year classes would begin to recruit to the fishery in 2012. This is further corroborated by the commercial and survey length frequency distributions, as well as the modal analysis of survey data, which show that the fishable biomass is currently dominated by the 2007-2008 year classes, with very little indication of strong succeeding (>2009) year classes. The paucity of the succeeding year classes is consistent with recent trends in the survey belly-bag index, which has been low for 2010-2012 (2009-2011 year classes). Indices of stock dispersion suggest that the stock is currently composed of several year classes, and is relatively evenly distributed on the fishing grounds. Trends in shrimp size indices are consistent with expectations based on life history and growth rates of moderately abundant shrimp (i.e. no evidence of slower growth or delayed sex transition that have occurred in this more abundant cohorts/high density periods in this stock). The continuation of warmer temperatures on the shrimp grounds, coupled with continued low abundance of most sympatric cold water species, do not provide an optimistic expectation of strong juvenile recruitment deriving from the 2007-2008 year classes. Low predation indices suggest that natural mortality of shrimp due to predation is likely to remain low. Total and spawning stock biomass are expected to remain stable at moderately high levels for 2013 as the 2008 year class undergoes sex transition and contributes fully to the fishable stock. The stock may begin to decline in 2014 as the 2007 year class begins to reach the end of its life-expectancy and because succeeding year classes do not appear to be very abundant. In the medium-term, the expectation of several years of weak recruitment to the adult (fishable) biomass, coupled with the lack of evidence of a new recruitment pulse and continued trends of warm temperatures and low recruitment of sympatric cold water species suggest that that the stock is likely to decrease starting in 2014.

RÉSUMÉ

Pour la troisième année consécutive, la moyenne stratifiée du relevé de Pêches et Océans Canada (MPO) et de l'industrie a connu une diminution, à savoir de 8 %; l'estimation de la biomasse est passée de 30 510 t en 2011 à 28 028 t +/- 4 560 t en 2012. Bien que la biomasse du stock reproducteur (BSR) ait aussi diminué de 12 %, elle demeure dans la zone saine pour ce stock. Une réduction préventive du total autorisé des captures (TAC) de 9 % en 2012 a aidé à garantir que l'indice d'exploitation des femelles (19 %) ne dépasse pas le point d'exploitation de référence pour ce stock (20 %). Dans l'ensemble, les indices du relevé et des captures par unité d'effort (CPUE) dans la pêche commerciale laissent entendre que le stock est relativement abondant, conformément à la prédiction voulant que le recrutement des classes d'âge 2007-2008 commence en 2012. Cette conclusion est aussi corroborée par la répartition de la fréquence des longueurs dans la pêche commerciale et le relevé ainsi que l'analyse modale des données du relevé, qui indiquent que la biomasse exploitable est actuellement dominée par les classes d'âge 2007-2008; il y a très peu d'indications que les classes d'âge subséquentes (après 2009) seront fortes. La faiblesse des classes d'âge subséquentes est conforme aux récentes tendances dans l'indice du relevé avec sac ventral, qui était bas pour la période de 2010 à 2012 (classes d'âge 2009-2011). Les indices de dispersion laissent supposer que le stock est actuellement composé de plusieurs classes d'âge et qu'il est réparti assez uniformément sur les lieux de pêche. Les tendances dans les indices de taille des crevettes sont conformes aux attentes basées sur les caractéristiques biologiques et les taux de croissance des cohortes relativement abondantes; c'est-à-dire, il n'y a aucun signe de croissance ralentie ou de changement de sexe tardif dans les cohortes plus abondantes et les périodes de densité élevée de ce stock. Les températures de plus en plus chaudes sur les lieux de pêche de la crevette, conjuguées à l'abondance de la plupart des espèces d'eau froide sympatriques qui demeure basse, ne donnent pas des attentes optimistes pour un fort recrutement des juvéniles des classes d'âge 2007-2008. Les faibles indices de prédation laissent supposer que la mortalité naturelle de la crevette due à la prédation demeurera probablement faible. La biomasse totale et la biomasse du stock reproducteur devraient demeurer stables à des niveaux relativement élevés en 2013 étant donné que la classe d'âge 2008 doit changer de sexe et contribuer pleinement au stock exploitable. Le stock pourrait commencer à diminuer en 2014, car la classe d'âge 2007 commencera à atteindre la fin de sa durée de vie et les classes d'âge subséquentes ne semblent pas très abondantes. À moyen terme, les prévisions concernant plusieurs années de faible recrutement à la biomasse adulte (exploitable), combinées au manque de preuves d'une nouvelle vague de recrutement et aux tendances continues de températures élevées et de faible recrutement des espèces d'eau froide sympatriques, laissent supposer que le stock va probablement diminuer à partir de 2014.

INTRODUCTION

The biology of northern shrimp, *Pandalus borealis*, is reviewed in Shumway et al. (1985) for various stocks world-wide, and by Koeller (1996a, 2000, 2006) and Koeller et al. (2000a, 2003a) for the eastern Scotian Shelf stock. The rationale for the assessment and management approach used is described in Koeller et al. (2000b). The history of the eastern Scotian Shelf shrimp fishery and recent stock assessments are given in Koeller (1996b), Koeller et al. (2011) and Hardie et al. (2012, 2013). Although there has been some shrimp fishing on the Scotian Shelf since the 1960s, the Nova Scotia fishery began to expand toward its full potential only when groundfish bycatch restrictions were overcome with the introduction of the Nordmøre grate in 1991 (Figure 1). The total allowable catch (TAC) was first reached in 1994, when individual Shrimp Fishing Area (SFAs) quotas were removed. With biomass at historical highs and continued good recruitment, the TAC was raised from 3100 mt to 3600 mt for 1997 and to 3800 mt for 1998. Despite evidence of reduced recruitment to the population, and because of continued high spawning stock biomasses (SSBs) and large year classes (1993-1995) recruiting to the fishery, the TAC was increased to 5000 mt for 1999 and to 5500 mt for 2000. With the strong year classes completing their life cycle; recruitment only average; a decreasing trend in the survey biomass; increasing exploitation rates; changes in the distribution of the resource; and increasing harvest levels during the ovigerous period, the TAC was reduced to 5000 mt for 2001 and to 3000 mt for 2002 and 2003. In 2003, the survey index increased for the first time following three successive declines and the TAC was raised to 3500 mt for 2004. Signs of improved recruitment in the form of a very strong 2001 year class suggested that the stock would continue to increase. The 2004 survey biomass was the highest on record and the TAC was raised to 5000 mt for the 2005 fishery. Despite a declining trend since 2004, biomass has remained relatively high, especially in SFA 14. Consequently, TACs were kept at 5000 mt for the 2006-2008 fisheries. With the 2001 year class at or past normal life expectancy, below average recruitment following, and a large biomass decrease in SFA 14, biomass was predicted to continue decreasing. Consequently, the TAC for 2009 was decreased to 3500 mt to prevent an increase in the exploitation rate. A problem with the angle of attack of the Nordmøre grate in the survey trawl was discovered and rectified for the 2009 survey. The survey abundance index increased nearly 50% to the second highest value on record in 2009. The degree to which this increase, and the underestimation of the population in preceding years, can be attributed to the degeneration and refurbishment of the survey trawl is discussed in Koeller et al. (2011). In general, the increase in the survey index in 2009 can be attributed to both the increased catchability with the refurbished trawl and increased biomass, the latter due, in part, to the unexpected continued contribution of the 2001 year class beyond its expected lifespan. As a result, the TAC for 2010 was set at 5000 mt. The trawl was carefully inspected prior to the 2010 survey, and replaced with a new trawl built to the specifications of the previous trawls in 2011. The Atlantic Canadian Mobile Shrimp Association (ACSMA) now oversees professional inspection and necessary maintenance of the survey trawl before (annually) and during (if necessary) the survey.

Since 1999, many shrimp stock assessments have included a "Traffic Light" analysis (Koeller et al. 2000b, Mohn et al. 2001, Halliday et al. 2001). The organisation of this report is based on this multiple indicator diagnostic approach, with discussion of individual indicators grouped under headings representing four "characteristics," in the order they are presented in the summary. In previous documents (e.g. Hardie et al. 2012, 2013), the methods used to calculate the indicators and their relevance to the characteristic they represent were described in the "Methods" section. In this document, the "Methods" section is a more general description of the data sources, with reference to past documents for detailed indicator calculation methodology, except where new approaches have been taken. The discussion of the relevance/interpretation

of each indicator to the characteristic that it represents is combined with the presentation of the 2012 results in the "Results and Discussion" section. Indicators always represent summary data for the entire area (i.e. all SFAs combined, according to the current practice of managing the fishery as one stock). The indicator series used in the analysis is given as an uncaptioned figure directly after the indicator heading. Where appropriate, the interpretation of the indicator time series themselves are supplemented by other data which are given as numbered and captioned figures and tables at the end of the document. For example, individual SFA data often replicate the indicator trends and thus substantiate them. Supporting data may be quite independent from the data used to derive the main indicator. For example, catch rates in the shrimp trap fishery supported the apparent increasing shrimp aggregation shown by the survey and catch per unit effort (CPUE) data; anecdotal reports of large numbers of age 1 shrimp found on Cape Breton beaches in 2002 supported survey data indicating a strong 2001 year class, etc. This additional information may be used in the interpretation of indicator trends in the "Results and Discussion," but it is not used in the summary traffic light "scores." In any case, it should be noted that such scoring is not intended to be translated directly into management action (e.g. in the form of rules linked to summary scores). The "Traffic Light" is currently seen simply as a tool for displaying, summarising, and synthesising a large number of relevant yet disparate data sources into a consensus opinion on the health of the stock.

A precautionary approach using reference points and control rules within the framework of the Traffic Light analysis was first reviewed during the Fisheries and Oceans Canada (DFO) Maritimes 2009 Regional Science Advisory Process (Figure 2). That approach has since been modified and included in the new Integrated Fisheries Management Plan in 2011 and was reviewed at a Regional Science Advisory Process in 2012 (Smith et al. 2012). In general, the precautionary application of reference points for eastern Scotian Shelf shrimp includes:

1. **Limit Reference Point (LRP)**: 30% of the average SSB (5459 mt) maintained during the modern fishery (2000-2010[1]). The LRP is approximately equal to the average SSB during the low-productivity (pre-1990) period for this stock, characterised by low shrimp abundance, high groundfish abundance and relatively warm temperatures. The Scotian Shelf shrimp population previously increased from a low level (approximately 4300 mt) during the transition from low- to high-productivity, so the working assumption is that shrimp could once again recover from this level given appropriate environmental conditions and fishing pressure (i.e. $B_{recover}$ proxy). Secondly, given the important role of shrimp in the Scotian Shelf ecosystem, particularly as prey for groundfish, this LRP is set to avoid a decrease in shrimp abundance below the level at which it was previously able to fulfill its ecosystem roles under a situation of high groundfish abundance (i.e. to avoid a scenario in which low shrimp abundance could act as a limiting factor in groundfish non-recovery).
2. **Upper Stock Reference (USR)**: 80% of the average SSB (14558 mt) maintained during the modern fishery (2000-2010*). The USR has been selected at the default value (80%) and to maintain a sufficient gap between the LRP and USR to account for uncertainty in the stock and removal reference values, and to provide sufficient time for biological changes in the population to be expressed, detected and acted upon.

[1] The reference points are set based on data from 2000-2010 to avoid a scenario whereby reference points based on a moving average would become *less* conservative during a period of a biomass downturn. This action does not negate the need to be vigilant for signs of a shift away from the current high productivity regime towards a lower productivity regime in which these reference points may no longer be suitable.

3. **Removal Reference Point**: The removal reference for Scotian Shelf shrimp is 20% female exploitation (actual female catch/SSB) when above the USR. This exploitation rate has rarely been exceeded during the modern fishery (2000-present), a period during which high CPUE and SSB have been maintained. Additionally, given that shrimp survive for approximately three to four years after their recruitment to the fishery, it can be approximated that on the order of 25-33% of the fishable biomass would be subject to natural mortality in any given year. As a result, the removal reference of 20% for shrimp is on the conservative side of this simplistic estimation of natural mortality (25-33%). Although exploitation scenarios in which fishing mortality equals natural mortality may result in optimal yield (e.g. Gulland 1971) this may be an overly risky exploitation strategy. As a result, the maximum removal reference of 20% for shrimp is on the conservative side of the simplistic approximate range of natural mortality (25-33%).

At SSB levels below the LRP the fishery is closed. A suite of approximately 20 secondary indicators of shrimp abundance and production, fishing effects and environmental conditions provide a scientific interpretation of holistic data to inform the way in which science advises responding to the stock status and removal relative to reference points.

The shrimp fishing areas on the Scotian Shelf are shown in Figure 3 and Table 1. Table 2 gives licensing information for the recent period covered under sharing agreements between the Nova Scotia and Gulf fleets. It currently operates under an 'evergreen' Integrated Fisheries Management Plan.

The experimental trap fishery was not under quota management from 1995-1998 except for a 500 mt precautionary "cap". As a result, the total catch tended to exceed the TAC due to the trap fishery. When the trap fishery in Chedabucto Bay was made permanent in 1999, a trap quota was set at 10% of the total TAC, e.g. 500 tons of the 5000 mt TAC. The reallocation of any uncaught portion of the trap quota late in the year resulted in some fishers being unable to take advantage of the additional quota. This often contributed to an overall catch lower than the TAC. In an attempt to avoid reallocations, in 2004, only 300 mt were allocated to this fishery, which was closer to its capacity. The trap allocation was reduced to 8% in 2005 and trap fishing effort and catch were very low during 2005-2010 due to poor market conditions. Market conditions improved in 2011-12. Total trap landings were 111 mt for 2011, and 130 mt (of 336 quota allocation) were landed as of November 20, 2012.

METHODS AND MATERIALS

TRAFFIC LIGHT INDICATORS

Default boundaries between traffic lights for individual indicators, i.e. transition from green to yellow and from yellow to red were arbitrarily taken as the 0.66 and 0.33 percentiles, respectively, of the data in the series, unless an increase was considered bad for stock health, in which case these were reversed. Note that for commercial CPUE series, the "polarity" of the default boundary should be considered with other indicators for certain years. For example, increased CPUE series coupled with increased aggregation and decreased survey abundance would be viewed as a negative development. Traffic lights were not changed from the default (Koeller et al. 2002) in this document. Data series vary in length from 11-31 years depending on the availability of data for each indicator. In contrast to past documents, a detailed description of the calculation of each indicator is not repeated here. Instead, only the data sources and any methodological changes since 2011 are discussed in detail. Otherwise, the methods used to calculate the 24 indicators that contribute to the Abundance, Production,

Fishing Effects and Ecosystem characteristics summarised in the Traffic Light analysis are given in Hardie et al. (2013) and previous documents.

DATA SOURCES

DFO-Industry Cooperative Trawl Survey

The 18th DFO-industry trawl survey, incorporating a mixed stratified random - fixed station design, was conducted in June 2012. Survey design and station selection methods were similar to annual surveys completed since 1995 (Hardie et al. 2013): fishing depths >100 fathoms, randomly selected stations in strata 13 and 15; fixed stations in strata 14 due to the difficulty in finding trawlable bottom; 30 minute tow length; and 2.5 knot vessel speed. Stations in strata 17 (inshore) were selected randomly at all depths having a bottom type identified as LaHave clay on Atlantic Geosciences Centre surficial geology maps.

The 2012 survey was completed by marine vessel (MV) *Cody & Kathryn*, which had also conducted the survey in 1995, 1998, 2009-2011. All surveys since 1997 were conducted using the standard trawl (Gourock #1126 2-bridle shrimp trawl and #9 Bison doors), which has been professionally maintained by the ACMSA since 2010. Biomass/population estimates (swept area method) and bootstrapped confidence intervals (Smith 1997) were calculated using the catch/standard tow (17.4 m x 1.25nm), i.e. the actual catch adjusted to the standard by the average measured wing spread (using NETMIND sensors) of the survey trawl during each tow and the actual distance travelled (Halliday and Koeller 1981).

The co-operative DFO-industry series, begun in 1995, used several different vessel-trawl combinations requiring comparative fishing experiments in 1996 and 1997 (Koeller et al. 1997). In order to obtain a wider range of indicator values for this series, it was extended to include DFO surveys conducted in 1982-1988, a period of low abundance in contrast to the present period of high abundance. There were no comparative fishing experiments that allowed direct intercalibration of the two survey series, consequently, catch data were only adjusted by the difference in the wing spreads of the trawls used. Wing spreads were based on the performance specifications of the trawl used for the earlier series, and from actual measurements for the latter series. However, it is probable that the trawl used during the recent series was more efficient in catching shrimp than during the 1982-1988 series, consequently, *the large differences in catch rates between the two series may be exaggerated and should be interpreted cautiously*. Since the cod end mesh size in both series was the same (40mm) size selectivities of the two series were assumed to be the same.

The chronology of survey vessels, gear changes and comparative fishing experiments are summarised below:

1995: *Cody & Kathryn* – used vessel's commercial net
1996: *Lady Megan* II – vessel's net, comparative fishing with *Cody & Kathryn*
1997: *Miss Marie* – survey trawl (new, built by Nordsea), comparative fishing with *Cody & Kathryn*
1998: *Cody & Kathryn* – survey trawl
1999-2001: *Carmel* VI (named *Amelie Zoe* in 1999) – survey trawl
2002-2003: *All Seven* – survey trawl (built by Pescatrawl)
2004-2008: *All Seven* – survey trawl (new in 2004)
2009: *Cody & Kathryn* – survey trawl (refurbished by Capt. Schrader)
2010: *Cody & Kathryn* – survey trawl (checked by Capt. Schrader and Morgan Snook)
2011: *Cody & Kathryn* – survey trawl (new in 2011)
2012: *Cody & Kathryn* – survey trawl (new in 2011)

Commercial Catch Data

Data on catch rates were obtained from fishers' logs required from all participants and provided by DFO Maritimes Region Statistics Branch. Commercial catch data from Gulf based vessels, which have the longest history in the fishery, provide a CPUE index as a simple unstandardised mean catch/hour fishes from all Gulf-based vessels in any given year. The shorter time series for the Nova Scotian fleet (19 years) is used to estimate a standardised CPUE series 1993-2012 derived from commercial catch data for the 27 Nova Scotian (<65') vessels that have fished for at least 7 of the 19-year series. Standardised CPUE data were limited to April-July inclusive, the months when the bulk of the TAC is generally caught. A generalised linear model was used to standardise commercial CPUEs with year, month, area, and vessel as categorical components. Predicted standardised CPUE values and confidence limits for a reference vessel, month, and area were then calculated for each year using the package predict.glm (R Development Core Team 2005). The data fit best to a Gaussian distribution (lowest Akaike information criterion value). Commercial counts (number of shrimp per pound) are recorded in commercial logs.

Detailed Shrimp Analysis (Survey and Port Samples)

A random sample of approximately eight pounds of shrimp was collected from each survey set and from the last set of each commercial trip (collected during the fishery in all areas from all fleet components including vessels <65' landing mainly in Louisbourg and vessels >65' landing mainly in Arichat), and frozen for detailed analysis (i.e. carapace length, individual weight, sex and egg developmental stage). One hundred and twenty survey samples (one each from the main survey trawl and belly bag at each station) and approximately 50 commercial samples (number of samples per month and area approximately allocated in proportion to temporal and spatial distribution of weight of landings) are analyzed annually. Because of the timing of the shrimp assessment relative to the collection and analysis of samples, the advice provided at the Regional Science Advisory Process meeting generally derives from only a portion of these samples (in 2012, 78 (41 main trawl, 37 belly-bag) survey samples and 26 commercial samples). Science staff have suggested that a later assessment date (*i.e.* late January or early February) would be more efficient and would allow for the provision of more robust advice based on the entire complement of samples. To date it has not been possible to accommodate the need to set a TAC in time for shrimp fishing to begin (January, in recent years). The feasibility of using an interim TAC to allow fishing to begin in January (if desired) and the provision of advice early in the calendar year based on complete analysis of all biological samples should be further explored.

Length Frequency Analysis

Survey population estimates (numbers) were determined by the swept area method using individual set length frequencies and weights caught, and a length-weight relationship. Survey population estimates by age group were then estimated by separating total population at length estimates from the swept area method into inferred age groups using modal analysis ("mixdist" in R; Macdonald and Pitcher 1979). The data were assigned to seven age bins which are interpreted as corresponding to ages 1-7. Modes corresponding to older ages are binned together as 5+ because the assignment of ages would be highly subjective for ages 6 and older. Fitting the data to seven ages provided a highly significant fit to the length frequency distribution (Chi-square, $p<0.001$).

Shrimp Size Indicators

Four different indicators of shrimp size are used (see details in Hardie et al. 2013): mean maximum size, mean size at sex transition, mean female size, and commercial counts. These

indices have previously been presented as simple mean point estimates without any measure of uncertainly. This year, confidence intervals have been added for the first time to aid in the identification of important changes in these time series. Methods used to calculate size indicators remain unchanged from Hardie et al. (2013), except for the mean female size indicator. Previously, this indicator was calculated as the overall annual average size of females from port samples collected throughout the fishery (pooled). Because the catch is composed mostly of females, this resulted in exceedingly narrow confidence intervals (due to very large pooled sample sizes of 10,000-15,000 shrimp). In order to be more consistent with other shrimp size indicators (except for commercial counts), an average was taken within each port sample (N=50 port samples) and the annual mean female size was then calculated, with confidence intervals, from those data.

Fishing During Ovigerous Period

This indicator has been excluded from the 2012 assessment due to concerns expressed during past assessments that the ovigerous period used for this index (August-March) may have shifted in recent years, and that it is unclear that the removal of fewer egg-bearing females (per unit weight) is more detrimental than the removal of more numerous females without eggs.

Ecosystem Data

Shrimp survey bottom temperatures are determined throughout each shrimp survey set with a continuous temperature recorder (Vemco Ltd.) attached to the headline of the trawl. Satellite data are used to estimate sea surface temperatures within defined rectangles encompassing the shrimp holes for February-March. The predation, capelin abundance, cod recruitment and Greenland halibut abundance indices derive from the summer groundfish survey which encompasses the shrimp holes (i.e. strata 443-445 and 459, details in Hardie et al. 2013). The snow crab recruitment index, as described in Hardie et al. (2013), is now shifted forward by one year in the Traffic Light Analysis (e.g. 2011 value used for 2012 Traffic Light Value) to solve the problem that the current-year value is generally not available in time for the shrimp assessment.

TRAFFIC LIGHT SUMMARY

Individual traffic light indicators were summarised using simple averaging. Each indicator is given a value according to its colour, i.e. green = 3, yellow = 2, and red = 1, and an average is calculated. This average is assigned a "summary colour" according to limits determined by the probability distribution of possible outcomes, i.e. the limits between red, yellow, and green are set so that each of the three summary colours has an equal probability of being assigned in a random set of individual indicator colours/values. The DFO Maritimes Regional Science Advisory Process review committee has emphasised that the summary is difficult to interpret and should not be the primary consideration in the advice, because issues such as weighting of indicators and harvest rules associated with any particular summary have not been resolved.

BYCATCH

The introduction of the Nordmøre grate in 1991 reduced bycatch and allowed the fishery to expand to its present size. Bycatch information from observer coverage of 55 commercial sets from 2012 (one trip from Gulf-based vessels; two trips from Nova Scotia vessels) suggests that Gulf and Nova Scotia fleet trawl configurations including the use of the Nordmøre grate continue to ensure low total bycatch (1.56%) by weight. It is noteworthy that this value is very likely over-estimated due to the minimum 1 kg weight recorded by the observers (e.g. a single sand lance would be recorded as 1 kg despite weighing only a few grams). Total bycatch by weight from observed trips in 2012 is approximately 50% lower than was summarised in 2010-2011 (Hardie et al. 2013), much closer to the 2008-2010 summary (1.78%) (Hardie et al. 2012). All observed

trips took place during the spring/summer when bycatch has been less than during the fall. There was no observer coverage in SFA 13 (an area where herring and capelin bycatch was much higher than in the other areas) due to lack of fishing in that area during 2012. Atlantic (Striped) Wolffish were caught in one observed commercial set (weighing less than 1 kg in total). Nonetheless, the eastern Scotian Shelf mobile shrimp fishery currently poses little risk in terms of bycatch amount or species-composition.

RESULTS AND DISCUSSION

PRECAUTIONARY APPROACH

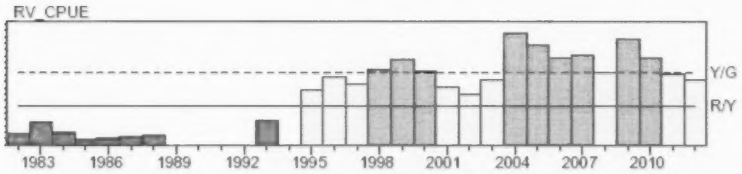
Spawning stock biomass (SSB) and female exploitation indices are reported in the Traffic Light (below), but these indices also define stock and removal reference points for Scotian Shelf shrimp. In this context, it is worth reiterating that SSB by itself is not a measure of reproductive capacity. Because the relationship between fecundity and size, and the dynamic range of shrimp size in response to fluctuations in density, temperature and growth rate, it is important to carefully consider the "Auxiliary Data" provided by the Traffic Light Indicators when interpreting the reference points depicted in Figure 2.

Traffic Light Analysis

Input data for the traffic light analysis are given in Table 3. These data are graphed in the uncaptioned figures immediately following the indicator headings in the section below.

ABUNDANCE

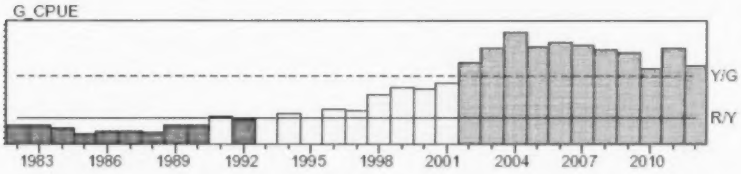
Research Vessel Survey Abundance Index



The stratified survey estimate for 2012 (representing a biomass of 27,978 mt using the swept area method) decreased by approximately 8% relative to the 2011 estimate. This is the third consecutive year of decline, which began after the near-record high in 2009 (figures 4-5; tables 4, 6). The biomass estimate for SFA 13 increased by 32% (following a 68% increase in 2011) but remains lower than other SFAs. The biomass estimate for SFA 14 decreased by 25%, following approximately 10% declines in the past two years. The distribution of survey catches during the last two years is shown in Figure 5.

Interpretation: The 2012 survey abundance index value is generally consistent with the 2012 values for the Gulf (Table 3) and Standardised CPUE indices (Figure 6A). Although both the Gulf and survey CPUE indices declined slightly, while the standardised CPUE index increases slightly, the changes were relatively minor and are consistent with the moderately abundant 2007-2008 year classes supporting the current fishable biomass.

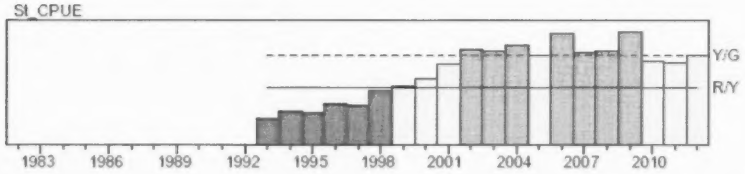
Gulf Vessels Catch per Unit Effort



The unstandardised Gulf vessel CPUE showed an increasing trend during the late 1980s to 2004 before stabilising at a relatively high level since that time. Although the 2012 value decreased slightly since 2011, it remains at a high level.

Interpretation: These are the largest vessels in the fleet and although the participating vessels (and fishing gear) have changed considerably since the beginning of the time series, they have always been >65' in length, compared to the <65' Nova Scotia fleet. This is an important time series, because it spans periods of both high and low abundance of the stock. However, since fishing methods and gear have improved over the years (*i.e.* introduction of Nordmøre grate in 1991), the differences in Gulf CPUEs between the period of low abundance (pre-1993) and the recent high abundances should be interpreted cautiously.

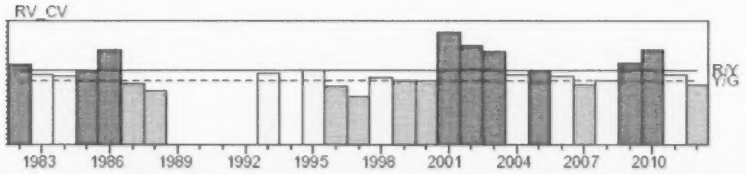
Commercial Trawler Standardised Catch per Unit Effort



The standardised CPUE indicator remained stable for 2012 at a relatively high level. This series follows a similar pattern to the Gulf series, showing an increasing trend until the early 2000s, fluctuations at a high level since, and a downturn for 2010 that is consistent with the other CPUE-based indicators.

Interpretation: The maintenance of relatively high catch rates for all fleet sectors suggests that shrimp remain relatively abundant, and is consistent with the current abundance of the relatively large 2007-2008 year classes in the fishable biomass. There have been two notable divergences between commercial CPUEs and the shrimp survey (*i.e.* 2000-2003 and 2005-2008 Figure 6A). The first divergence was attributed to distributional changes associated with the demise of the large 1995 year class. The second divergence appears to be, at least in part, due to problems with the survey trawl (Koeller et al. 2010).

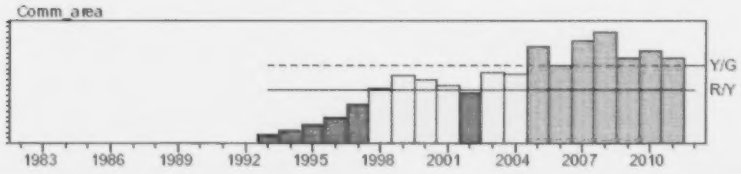
Research Vessel Survey Coefficient of Variation



The survey measure of dispersion (overall CV) decreased for the second consecutive year (Figure 7).

Interpretation: The return of this indicator to a lower value suggests that the resource is currently fairly evenly dispersed on the fishing grounds, which is consistent with a moderately abundant resource. The fact that the survey and commercial CPUE trends have been quite consistent in recent years, including 2012, and the general stability catch rates over commercial fishing area (below) provides further support for this (i.e. the fishery is unlikely to be maintaining high catch rates by targeting aggregations of a declining resource).

Commercial Fishing Area

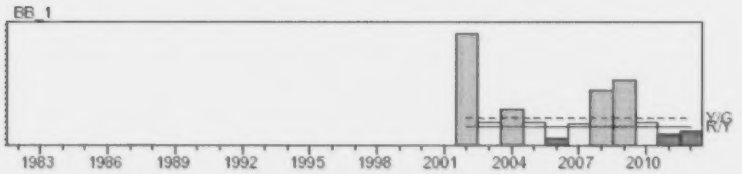


The area with commercial catch rates >250 kg/h decreased slightly for the third consecutive year in 2011 (Figure 8, top). Overall, the trends in areas of various ranges of catch rates have been stable for the past five years (Figure 8, bottom), with the exception that the areas of highest catch rates (>450 kg/h) have declined throughout that period. The spatial distribution of effort did not change appreciably between 2011 and 2012 (Figure 9).

Interpretation: This measure of dispersion is particularly important when survey indices are decreasing while commercial catch rates continue to increase (in which case, a decrease in this index could indicate a concentration of the remaining stock in a smaller area). This is not currently the case, given that survey and commercial catch rates have been quite consistent in recent years, including 2012. The relative stability of this index, coupled with consistent survey and commercial catch rates, little change in the spatial distribution of effort, and relatively low survey coefficient of variation (CV) of survey, are consistent with a moderately abundant stock that is quite evenly distributed on the fishing grounds.

PRODUCTION

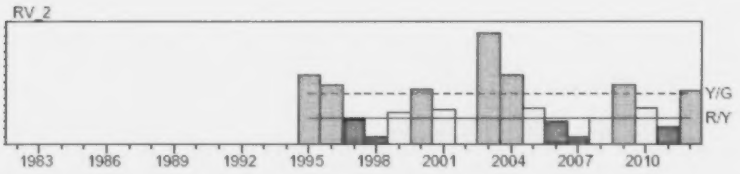
Research Vessel Survey Belly-bag Abundance at Age 1



The index of age 1 abundance was low again in 2012 (Table 5). This index shows considerable dynamic range despite only 11 years of data. It correctly predicted the strength of the 2001 year class at age 1 in 2002, two years before it began to show up in commercial catches, and as many as five years before it was fully recruited to the fishery (figures 10-12, Table 5). The apparent strength of the 2007 and 2008 year classes as 1 year olds in the 2008 survey supports the hypothesis that a pulsed recruitment pattern has been established, similar to the snow crab stock in the same area but with a cycle of six to seven years, about equal to the species life cycle. If these year classes hold up as strong, this would make three such pulses since the modern fishery began, i.e. associated with the 1994-1995, 2001, and 2007-2008 year classes. The appearance of recruitment cycles of different lengths provides evidence that some form of a stock recruitment relationship exists i.e. strong year classes result in large spawning stocks, resulting in strong year classes

Interpretation: The low value of the age 1 abundance index suggesting that juvenile recruitment was poor once again in 2012. The 2007-2008 year classes were expected to begin to contribute to SSB (and juvenile recruitment) in 2012, which would not be expected to show in the belly bag until 2013. At present, no funding has been secured for a science survey in 2013, in which case, this source of information will not be available. It is important to consider that various environmental influences are also understood to strongly influence shrimp recruitment (e.g. spring sea surface temperatures and predator abundance, see below).

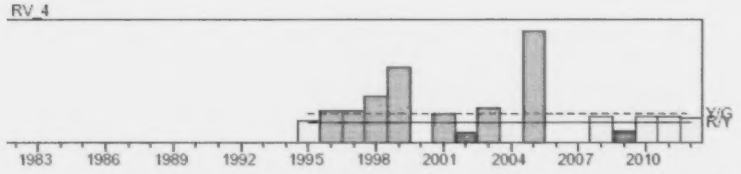
Research Vessel Survey Abundance at Age 2



The index of age 2 shrimp increased in 2012 (Table 5).

Interpretation: Trends between indices of age 1 and age 2 abundance remain somewhat equivocal (i.e. changes in the age 1 index are not always followed by concomitant changes in the age 2 indicator the following year, Table 5). Although the length frequency modal analysis tends to clearly define the age 2 mode, it is possible that this size of shrimp is not well (quantitatively) sampled by the main survey trawl.

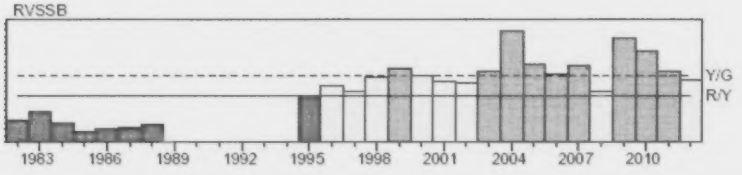
Research Vessel Survey Abundance at Age 4



The abundance of age 4 shrimp has remained stable for the past three years. This age class is currently composed of the 2008 year class likely in its last year as males. In 2000, and again in 2006 and 2007, this age could not be distinguished from the large mode attributed mainly to the large 1995 and 2001 year classes, respectively (Table 5, Figure 12). In several cases, this index has reflected recruitment pulses first seen in the belly-bag 4 years before (e.g. 1995 year class in 1999 age 4 index, 2001 year class in 2002 belly bag and 2005 age 4 index, and 2007-08 year classes in 2008-09 belly bag and 2011-12 age 4 index; Table 5).

Interpretation: The stability of the age 4 index in 2012 reflects the relatively abundant 2008 year class in their last year as males (usually), following the similarly abundant 2007 year class as age 4 last year. As was the case for the 2007 year class as age 4 in 2011, the 2008 year class is expected to provide good recruitment to the female population in 2013.

Research Vessel Survey Spawning Stock Biomass (Females)

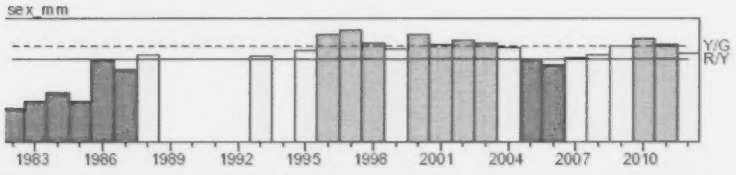


Spawning stock biomass (SSB) decreased for the fourth consecutive year (14,763mt, Figure 13, top). It remains in the healthy zone, although very near the upper stock reference (14,568mt, Figure 2). Although confidence limits around the SSB point estimate are not quantified, there is some uncertainty around this index, so the close proximity of the SSB estimate to the USR suggests that there is some likelihood (approximately 40% chance) that the true value falls within the Cautious Zone.

Interpretation: A clear stock-recruitment relationship has not yet been described for Scotian Shelf shrimp, although it has been for some other pandalid stocks (Hannah 1995, Boutillier and Bond 2000). Beginning in the late 1980s, SSBs increased from approximately 4300mt to values nearly three-fold higher by the mid 1990s. However, these increases occurred under specific environmental conditions (cold water temperatures and decreasing natural mortality due to predation) and negligible fishing mortalities, so 4300 mt should be considered the very lowest that the stock should be allowed to decline, and a more conservative value (5459 mt) is used as the LRP for this stock. SSB by itself is not a measure of reproductive capacity. Since fecundity is directly related to size, it should be considered in conjunction with the shrimp size indicators. In addition, multiparous females tend not to spawn every year.

The first of the strong 2007-2008 year classes were expected to recruit to the SSB in 2012 (DFO 2012), so the observed decrease, albeit a small one, was not expected. Although the SSB remains in the healthy zone, this should be interpreted with caution. The index has been declining since 2009, and with the exception of the moderately abundant 2007-2008 year classes, there is little promise of strong recruitment to the adult population after 2013. On a positive note, most indices of shrimp size, which had showed decreasing trends in 2011, appear to be stable or increasing in 2012 (below, Figure 14).

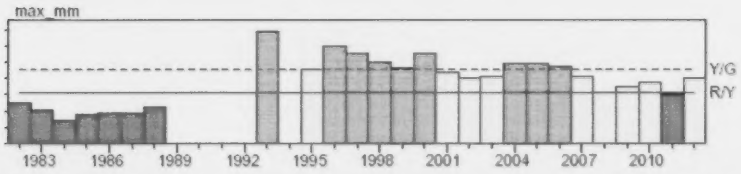
Average Size at Sex Transition (L_t)



This indicator decreased slightly for the second consecutive year although this change (2011-2012) may not be biologically significant relative to variability in the data (Figure 14D).

Interpretation: Delayed sex-transition occurs during periods of high population density, and results in extra years of growth, which in turn results in the production of larger females. This is consistent with increases in this value throughout the high-density period associated with the recruitment and passage of the 2001 year class through the fishery and with the current decrease given the ongoing population downturn.

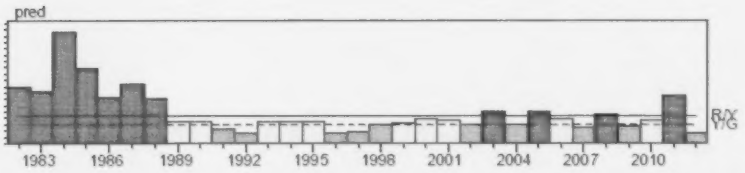
Average Maximum Size (L_{max})



The index of average maximum size increased slightly in 2012, although the current value is within the range of uncertainty in these data in recent years (Figure 14B).

Interpretation: The ratio of size at sex transition to maximum size was hypothesised to be constant (invariant) at about 0.8-0.9 for all stocks of *P. borealis* (Charnov and Skúladóttir 2000). This rule was shown to apply to the Scotian Shelf (Koeller et al. 2003b, Koeller 2006). Consequently, maximum size attained in the population is an indicator of growth, *i.e.* change in maximum size is probably indicative of a change in growth rate. The relationship between L_t or L_{max} to changes in growth rate is complex due to the influence of other factors including concurrent changes in longevity and natural mortality (e.g. slower growing shrimp tend to live longer). The relative stability of the mean maximum size index in recent years is consistent with other indicators that suggest that the stock is moderately abundant and stable.

Predation

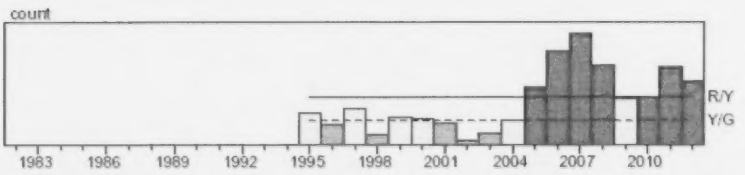


After two decades of very low values, the 2011 groundfish abundance index rose sharply to a level similar to those observed in the early 1980s when the shrimp population was low. In 2012, this index of predation on shrimp fell to one of the lowest on record.

Interpretation: Groundfish abundance is negatively correlated with shrimp abundance on the Scotian Shelf and in most other shrimp fishing areas. Based on the 2012 value, natural mortality due to predation is expected to be very low, similar to most years in the past two decades.

FISHING IMPACTS

Commercial Counts

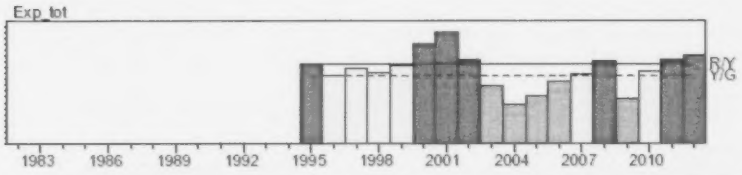


This indicator is a measure of the ease or difficulty fishers are having in "making the count," i.e. getting the best price for their shrimp. An increase in the count could indicate that a) recruitment is good and there are so many small shrimp it is difficult to avoid them or b) the population of larger shrimp is declining, or a combination of a) and b). Moreover, an increase in this indicator can be considered good (increased recruitment) or bad (growth overfishing) depending on whether it is placed in the production or fishing effects characteristic. Consequently, this indicator must be considered with others including abundance indices of the different age categories. Note that counts also change considerably during the fishing season, usually starting relatively high, decreasing to a minimum in July, and increasing thereafter, probably due to size specific changes in vertical and\or geographic distribution associated with changes in day length.

Interpretation: The commercial count decreased slightly in 2012 (Figure 14A), which is consistent with relatively small increases in mean female size and mean maximum size. The sharp rise to a peak in 2007 was associated with the maximum catchability of the 2001 year class which has dropped since that time as less abundant year classes now make up the

commercial catch. The stability of this indicator is consistent with other indices of abundance and length-frequencies of survey and commercial data that suggest that the stock is relatively abundant and stable.

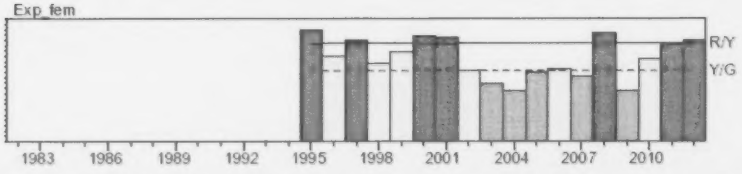
Exploitation Index



Assuming that the entire TAC (4200 mt) is caught in 2012 (87% caught as of November 20), the total exploitation index will be 15%, a slight increase relative to 2011 (Figure 13). The research vessel biomass estimate has been shown to be underestimated by as much as 25% because of lack of coverage in shallow areas surrounding the shrimp holes; consequently, the exploitation rate is probably overestimated. This indicator is therefore considered an index of exploitation. Since the survey uses a common commercial trawl with a Nordmøre grate, its selectivity is similar to commercial gear. The biomass used to estimate exploitation can be considered a point estimate of "fishable biomass."

Interpretation: The relative stability of the 2012 exploitation index relative to 2011 reflects the fact that the approximately 8% reduction in the 2012 biomass estimate has been offset by the approximately 9% TAC reduction (4600-4200mt) adopted as a precautionary measure in light of smaller year classes recruiting to the fishable biomass in upcoming years.

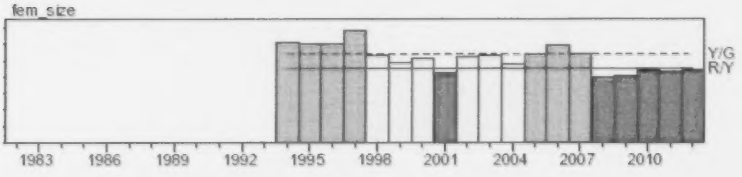
Female Exploitation Rate



Female exploitation is of interest because the shrimp fishery is selective for the larger females. It can be considered one measure of the impact of fishing on the reproductive potential of the stock. Based on preliminary data in 2011, female exploitation was estimated to have slightly exceeded the 20% removal reference point (DFO 2012). Re-analysis based on the complete 2011 dataset reduced the estimate to a value slightly below the reference point (18.6%). Based on preliminary data for 2012, female exploitation (18.9%) remains slightly below the removal reference (Figure 2, Figure 13 – bottom).

Interpretation: As was the case for total exploitation, the stability of the female exploitation index for 2012 reflects the fact that the approximately 9% precautionary reduction in the TAC for 2012 helped to compensate for the approximately 12% decrease in SSB.

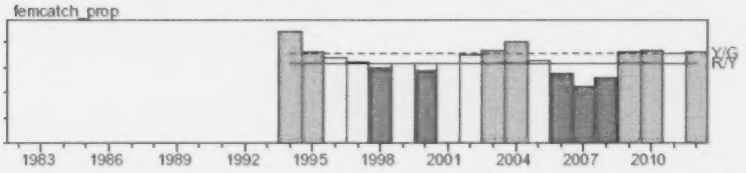
Mean Size of Females in Catch



A decrease in this indicator could indicate a decrease in the number of larger shrimp in the population due to fishing removals and an increased reliance on smaller animals, *i.e.* possible growth overfishing and/or recruitment overfishing. The average size of females in the catch has decreased from the early years of the fishery as the larger animals were selectively removed from the population.

Interpretation: The sharp decrease in 2008 was due to the sex transition of the slow growing 2001 year class as small females. Female size has been relatively stable since then, showing a slowly increasing trend as faster-growing shrimp from the less abundant succeeding year classes recruit to the female population. Overall, the average size of females in the catch has been relatively stable at a small size for the past five years (Figure 14C).

Proportion of Females in Catch

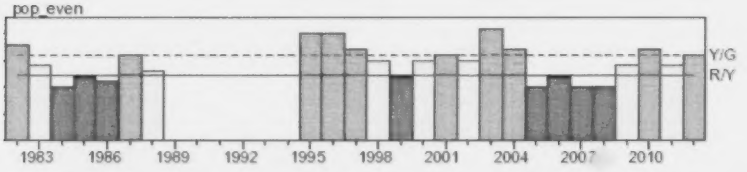


The proportion of females in the catch has been relatively stable at a high value since 2009 (Table 3).

Interpretation: The proportion of females in the catch decreased between 2004 and 2006 due to the increase in the proportion of 2001 year class males. The increase in 2007-2010 was due to the sex change and recruitment to the female population of this year class and the delayed sex-transition of abundant 4+ males observed in 2009. The relative stability of this index at a high value in recent years reflects the fact that the population is currently dominated by older shrimp, mostly female, with relatively poor year succeeding year classes (fewer males), which is also apparent in survey and commercial length frequency distributions (figures 10-12).

ECOSYSTEM

Population Age-length Evenness



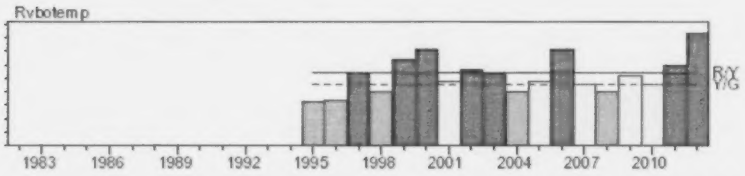
Population evenness was high at the beginning of the survey series in 1995 when the fishery was relatively new (it first attained the TAC only in 1994). It declined in the late 1990s as the large 1994-1995 year classes dominated the population, and was very low once again in 2003-2006 as the 2001 year class dominated. Since the end of the long-lived 2001 year class in 2009, the index has been fluctuating around a relatively high value.

Interpretation: This indicator is placed under the ecosystem characteristic assuming that evenness is related to the population's robustness or resiliency to various perturbations within the ecosystem, but it could also have been placed under fishing effects, since fishing will remove the largest/oldest length/age classes, or production, since an even length/age distribution implies stable recruitment. On the other hand, this index will also respond to the

passage of an exceptional year class through the population, which may not be a negative development if the abundance of other year classes remains relatively stable.

The 2012 value and relative stability of this index is consistent with a population composed of several year classes, most notably the relatively abundant 2007 and 2008 year classes that make up the bulk of the fishable biomass as 4-5 year old shrimp mature male, transitional and primiparous females. However, the paucity of succeeding year classes since 2008 (figures 10-12, Table 5) should not be overlooked.

Research Vessel Survey Bottom Temperatures

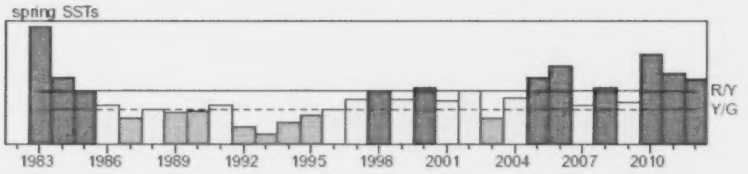


For some Northern Shrimp stocks near the southern limits of the species' range, abundance is negatively correlated with water temperatures. It is hypothesised that warmer water temperatures have a negative influence on shrimp populations because of the decreased fecundity associated with increased growth rates, decreased size at transition, and decreased maximum size as described above. Recent work also indicates that colder bottom temperatures increase egg incubation times resulting in later hatching times, which are closer to favourable spring growing conditions (warmer surface water and the spring phytoplankton bloom) (Koeller et al. 2009). On the eastern Scotian Shelf, the large population increase that occurred from the mid 1980s to the mid 1990s is associated with colder surface and bottom water temperatures. Large fluctuations in bottom water temperatures may also be associated with the cyclical recruitment pattern experienced since the early 1990s (i.e. 1993-1995, 2001 and 2007-2008 year classes).

Bottom temperatures on the shrimp grounds were relatively high during the 1980s, when the shrimp population was low, and it was low during the population increase of the 1990s (figures 15-16). Higher temperatures preceded the population downturn in 2001-2003 and the low belly bag index values for 2006-2007. Bottom temperatures during the shrimp survey increased again in 2012 (figures 15, 16).

Interpretation: Colder temperatures in 2007-2008 may have helped larval survival, as measured by belly bag results, by increasing the incubation period, bringing hatching times closer to the spring bloom and vernal warming of surface waters, conditions favourable for larval growth and survival. Similarly, the warmer temperatures in 2005, 2006 and 2009 are consistent with the low belly bag index results in 2006, 2007 and 2010, respectively (Figure 16, Table 5). The high value of this index for 2012 coupled with the high value for spring sea surface temperature (below) contributes to the expectation of poor recruitment of the 2012 year class.

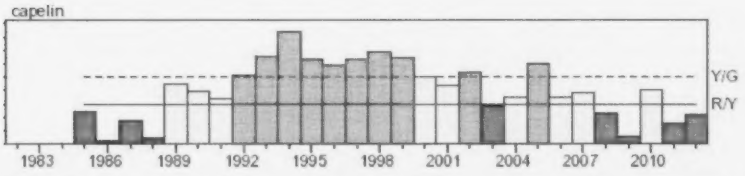
Spring Sea Surface Temperatures



Negative correlations between SSTs and lagged population estimates (four to five years in Gulf of Maine) are common for the southern *P. borealis* stocks, including the Scotian Shelf. This may be related to water-column stability and the match-mismatch of resulting phytoplankton bloom conditions with hatching times as hypothesised by Ouellet et al. (2007). Accordingly, SSTs used were averages for a period encompassing average hatching times on the Scotian Shelf (mid February to mid March). On the Scotian Shelf, the below average temperatures prevalent during the late 1980s and early 1990s may have facilitated the high abundances in the mid to late 1990s associated with the strong 1994-1995 year classes. However, at least one exceptional recruitment event occurred recently (2001) despite relatively high SSTs. The spring sea surface temperature index decreased slightly in 2012 but remains higher than the long-term average (Figure 15).

Interpretation: Spring surface temperatures remained high in 2012, and shrimp survey bottom temperatures increase to the highest on record, which could have a negative effect on the 2012 year class, and would be a concern for the shrimp stock if the warming trend continues.

Research Vessel Survey Capelin Abundance

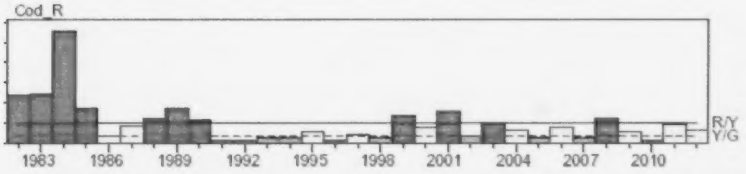


Capelin is among the most common bycatch species, both in the Scotian Shelf shrimp fishery and the June shrimp survey. They have been shown to increase in abundance during cold periods, which are also favourable for shrimp recruitment, and so can be considered a sympatric species (e.g. Frank et al. 1994). Their presence can therefore be considered an indicator of conditions favourable to the production of shrimp.

During the last 10 years, capelin abundance has been lower on average than the relatively high values between 1993 and 1999, and was especially low (near those of the 1980s when shrimp abundance was low) in 2008-2009. Capelin abundance remained low in 2012.

Interpretation: The low index for 2012 for this species suggests that recent/current environmental conditions are not favourable for recruitment of sympatric cold water species such as capelin and shrimp.

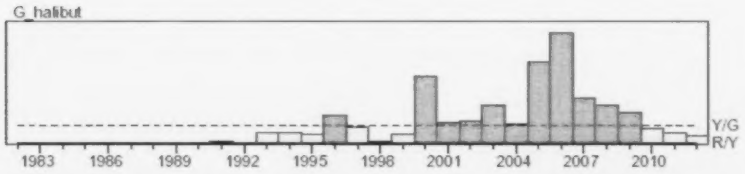
Cod Recruitment



Cod abundance is generally negatively correlated with shrimp abundance for most north Atlantic stocks, including the Scotian Shelf. This is probably partly due to large scale environmental influences, such as temperature, which appear to have opposite effects on cod and shrimp population dynamics, as well as a trophic effect of cod predation on shrimp. Cod recruitment (<30 cm) decreased in 2012, but still remains well below values seen in the 1980s.

Interpretation: Natural mortality of shrimp due to cod predation is likely to remain low.

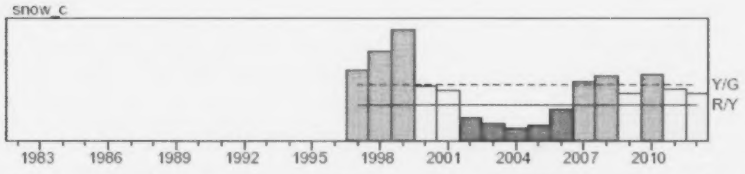
Greenland Halibut Recruitment



Greenland halibut is a cold water species whose abundance is often positively correlated to shrimp abundance. However, it should be noted that Greenland halibut are also known predators of shrimp, and so an increase in this indicator is both positive and negative. Restricting this indicator to juvenile halibut may decrease the influence of predation and have some predictive value for shrimp abundance. Greenland halibut <30 cm have been abundant on the eastern Scotian Shelf in the past decade, but have been decreasing steadily during the last six years. This species was rarely found during the warmer period of the 1980s when shrimp and capelin were also low in abundance.

Interpretation: The decreasing trend for this index over the past six years is consistent with the low value for capelin and suggests that recent/current environmental conditions are not favourable for recruitment of sympatric cold water species such as Greenland halibut, capelin and shrimp.

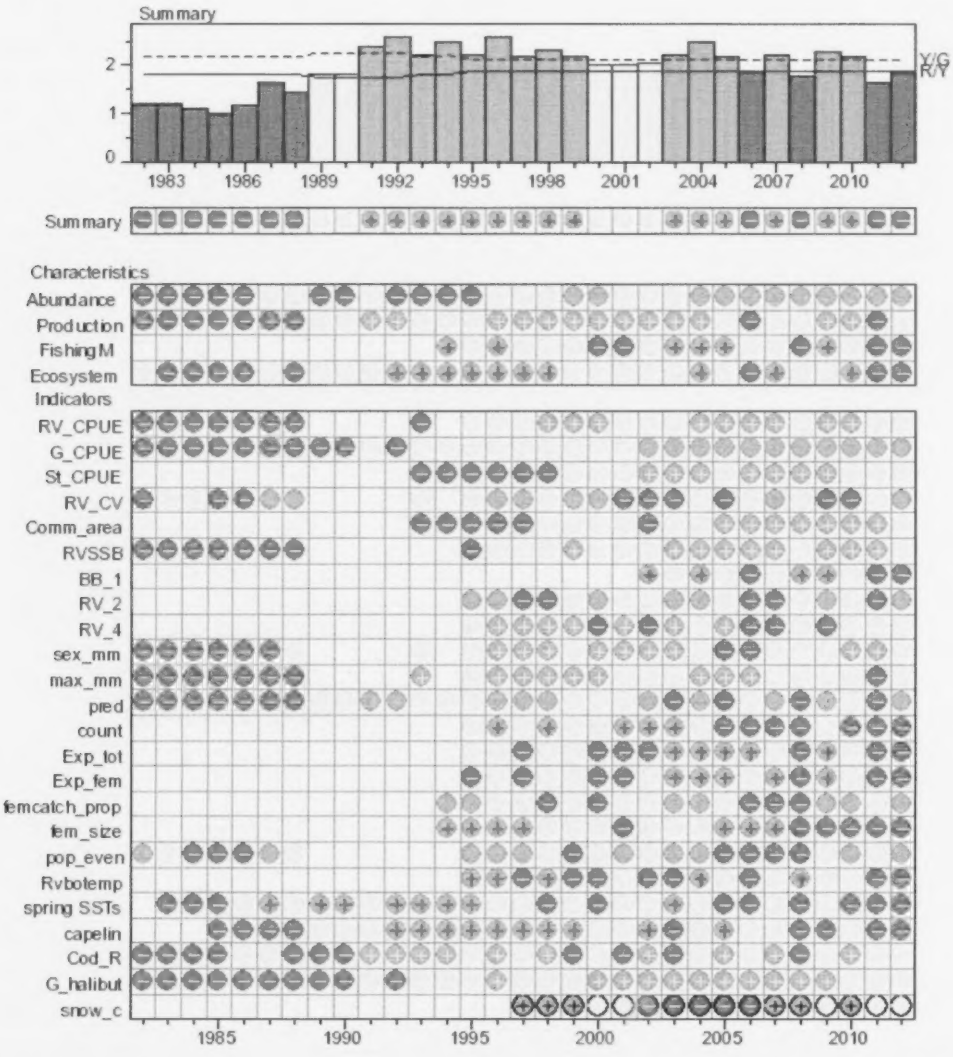
Snow Crab Recruitment



Snow crab abundance, as with Greenland halibut and capelin, tend to track shrimp abundance in the long-term, however, snow crab have considerably longer longevities and population cycles. The male pre-recruit index from the snow crab survey off southern Cape Breton has been high and relatively stable since 2007.

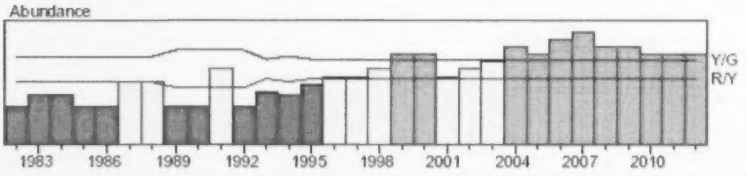
Interpretation: Although the snow crab recruitment index has decreased gradually for the past three years it remains at a relatively high level, compared to the early 2000s. In contrast to recent low index values for other sympatric species (above), the relative stability of the snow crab recruitment index suggests that environmental conditions are favourable for recruitment of sympatric cold water species such as shrimp and snow crab.

TRAFFIC LIGHT SUMMARY

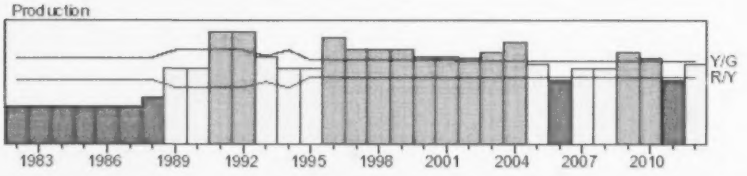


Precautionary Note: The overall summary and characteristic summary values are derived by a simple averaging process which does not account for complex interactions between indicators which may be occurring. Consequently, even the interpretation of individual indicators must be approached cautiously with regard to their relationship to stock health. Their placement within characteristics is also open to interpretation.

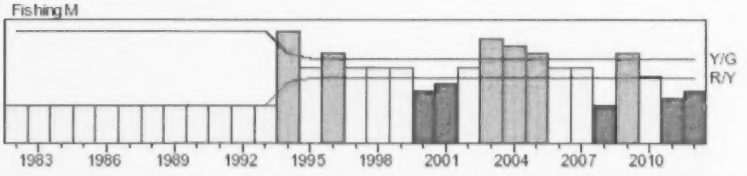
The summary indicator for 2011 remained red after the complete 2011 data were updated from all sources. In 2012, the Traffic Light analysis of preliminary survey and commercial data improved slightly relative to the 2011 summary, although it remained red. In general, the Abundance characteristics remained green, while the Production (red to yellow), Fishing Effects (remained red) and Ecosystem (remained red) characteristics improved.



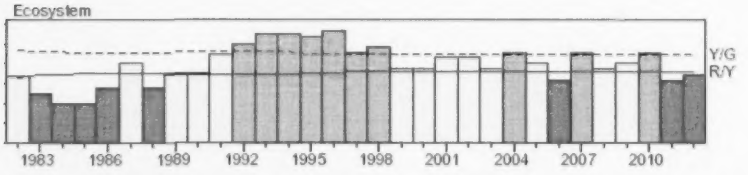
The Abundance characteristic has remained favourable (green) for the last nine years due to the influence of the commercial CPUE indices which remained strong throughout the downturn in the survey index from 2005-2008. In 2012, the survey and commercial CPUE indices remained relatively stable, with minor downturns in the survey and Gulf CPUE data offset by improvements in the CV of survey catches and relative stability in the area of moderate commercial catch rates.



The Production characteristic improved in 2012 due mostly to increased abundance of age 2 shrimp and a reduced finfish predator abundance index. However, SSB remains at a healthy level and the relatively abundant age 4 shrimp are expected to recruit to the female portion of the population in 2013.



The Fishing Effects characteristic remained relatively unchanged (red) for 2012. Total and female exploitation remain relatively high, although stability was achieved because total and SSB downturns were met with precautionary TAC reductions. Changes in most other indicators are minor.



The 2012 Ecosystem characteristic remained red because of unfavourable (high) temperature indices and low indices of sympatric species abundance.

SOURCES OF UNCERTAINTY

DFO-industry shrimp survey results are associated with high variances and biases associated with survey gear changes. Spatial and temporal variability in the distribution of shrimp is a source of uncertainty with regard to the accuracy of survey estimates; the survey is conducted consistently during the first ten days of June to try to mitigate this effect. In 2007-2008 problems with NETMIND distance sensors and data logging required use of historical average instead of

actual wing spread data to calculate swept areas and abundance. The trend in commercial catch rate has not always been consistent with the trend in the shrimp survey index; the possible reasons for these divergences have been discussed previously, and have been less problematic in recent years. The assignment of modal (length) groups of shrimp to age classes is somewhat subjective, particularly for larger individuals. Growth rates can decrease dramatically due to density dependence, as happened with the strong 2001 year class. Consequently, recruitment to the fishery can be delayed and spread over a longer time period. Unforeseen changes in the ecosystem (e.g. predators), and the environment (e.g. temperature) together increase the difficulty of making long-term projections.

ACKNOWLEDGEMENTS

The authors thank Captain Bob Schrader for his excellent co-operation and expert advice on the survey gear, and the entire crew of MV *Cody & Kathryn* for successfully conducting the 2012 survey. Thanks again also to the many fishers and buyers who provided fishery data such as counts, catch and effort data, and shrimp samples for laboratory analysis over the years. The authors also thank reviewers Jae Choi and John Tremblay for their constructive comments.

REFERENCES

Boutillier, J.A., and J.A. Bond. 2000. Using a fixed escapement strategy to control recruitment overfishing in the shrimp trap fishery in British Columbia. J. Northwest Atl. Fish. Sci. 27: 261–271.

Charnov, E., and U. Skúladóttir. 2000. Dimensionless invariants for the optimal size (age) of sex change. Evol. Ecol. Res. 2: 1067-1071.

DFO. 2012. Assessment of Northern shrimp on the eastern Scotian Shelf (SFAs 13-15). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/001

Frank, K.T., J. Simon, and J.E. Carscadden. 1994. Recent excursions of capelin (*Mallotus villosus*) to Scotian Shelf and Flemish Cap during anomalous hydrographic conditions. NAFO SCR Doc. 94/68.

Gulland, J.A. 1971. The fish resources of the ocean. Fishing News Books, West Byfleet, UK.

Halliday, R.G., and P.A. Koeller. 1981. A history of Canadian groundfish trawling surveys and data usage in ICNAF Divisions 4TVWX; pp. 27-41. In W.G. Doubleday and D. Rivard (Editors). Bottom Trawl Surveys. Can. Spec. Publ. Fish. Aquat. Sci. 58.

Halliday, R.G., L.P. Fanning, and R.K. Mohn. 2001. Use of the traffic light method in fishery management planning. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/108.

Hannah, R.W. 1995. Variation in geographic stock area, catchability, and natural mortality of ocean shrimp (*Pandalus jordani*): some new evidence for a trophic interaction with Pacific hake (*Merluccius productus*). Can. J. Fish. Aquat. Sci. 52: 1018–1029.

Hardie, D., M. Covey, M. King, and B. Zisserson. 2012. Scotian Shelf shrimp 2010-2011. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/ 102.

Hardie, D., M. Covey, M. King, and B. Zisserson. 2013. Scotian Shelf shrimp 2011-2012. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/033.

Koeller, P. 1996a. Aspects of the biology of pink shrimp *Pandalus borealis* Krøyer on the Scotian Shelf. DFO Atl. Fish. Res. Doc. 96/9.

Koeller, P. 1996b. The Scotian Shelf shrimp fishery in 1995. DFO Atl. Fish. Res. Doc. 96/8.

Koeller, P. 2000. Relative importance of environmental and ecological factors to the management of the northern shrimp fishery (*Pandalus borealis*) on the Scotian Shelf. J. Northw. Atl. Fish. Sci. 27: 37-50.

Koeller, P. 2006. Inferring shrimp (*Pandalus borealis*) growth characteristics from life history stage structure analysis. J. Shell. Res. 25: 595-608.

Koeller, P., M. Covey, and M. King. 1997. The Scotian Shelf shrimp (*Pandalus borealis*) fishery in 1997. DFO Atl. Fish. Res. Doc. 97/125.

Koeller, P., R. Mohn, and M. Etter 2000a. Density dependant sex change in pink shrimp, *Pandalus borealis,* on the Scotian Shelf. J. Northw. Atl. Fish. Sci. 27: 107-118.

Koeller, P., L. Savard, D. Parsons, and C. Fu. 2000b. A precautionary approach to assessment and management of shrimp stocks in the Northwest Atlantic. J. Northw. Atl. Fish. Sci. 27: 235-247.

Koeller, P., M. Covey, and M. King. 2002. A new traffic light assessment for northern shrimp (*Pandalus borealis*) on the eastern Scotian Shelf. DFO Can. Sci. Advis. Sec. Res. Doc. 2002/006.

Koeller, P., M. Covey, and M. King. 2003a. An assessment of the eastern Scotian Shelf shrimp stock and fishery for 2003. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/005.

Koeller, P., M. Covey, and M. King. 2003b. Is size at transition a measure of growth or abundance in Pandalid shrimp? Fish. Res. 65: 217-230.

Koeller, P., C. Fuentes-Yaco, T. Platt, S. Sathyendranath, A. Richards, P. Ouellet, D. Orr, U. Skúladóttir, K. Wieland, L. Savard, and M. Aschan. 2009. Basin-scale coherence in phenology of shrimps and phytoplankton in the north Atlantic Ocean. Sci. 324: 791-793.

Koeller, P., C. Fuentes-Yaco, M. Covey, M. King, and B. Zisserson. 2011. The last traffic light on the Scotian Shelf: Shrimp 2009-2010. An assessment of the eastern Scotian Shelf shrimp stock and fishery in 2008 and outlook for 2009. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/061.

Macdonald, P.D.M., and T.J. Pitcher. 1979. Age-groups from size-frequency data: A versatile and efficient method of analysing distribution mixtures. J. Fish. Res. Board Can. 36: 987-1001.

Mohn, R., J. Black, and P. Koeller. 2001. Traffic light indicators. BIO Review 2000. 88 p.

Ouellet, P., L. Savard, and P. Larouche. 2007. Spring oceanographic conditions and northern shrimp *Pandalus borealis* recruitment success in the north-western Gulf of St. Lawrence. Mar. Ecol. Prog. Ser. 339: 229-241.

R Development Core Team. 2005. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Shumway, S.E., H.C. Perkins, D.F. Schick, and A.P. Stickney. 1985. Synopsis of biological data on the pink shrimp, *Pandalus borealis* Krøyer, 1838. NOAA Tech. Rept. NMFS 30.

Smith, S.J. 1997. Bootstrap confidence limits for groundfish trawl survey estimates of mean abundance. Can. J. Fish. Aquat. Sci. 54: 616-663.

Smith, S.J., H. Bourdages, J. Choi, E. Dawe, J.S. Dunham, L. Gendron, D. Hardie, M. Moriyasu, D. Orr, D. Roddick, D. Rutherford, B. Sainte-Marie, L. Savard, P. Shelton, D. Stansbury, M.J. Tremblay, and Z. Zhang. 2012. Technical guidelines for the provision of scientific advice on the precautionary approach for Canadian fish stocks: Section 7 – invertebrate species. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/117.

TABLES

Table 1. Total allowable catches (TACs; trawls) and catches (trawls and traps) from the eastern Scotian Shelf shrimp fishery (SFAs 13-15), 1980-2012.

Year	TAC Trawl	TAC Trap	Trawl Catch SFA 13	SFA 14	SFA 15	Total	Trap Catch	Total Catch
1980	5021	-	491	133	360	984	-	984
1981	-	-	418	26	10	454	-	454
1982	4200	-	316	52	201	569	-	569
1983	5800	-	483	15	512	1010	-	1010
1984	5700	-	600	10	318	928	-	928
1985	5560	-	118	-	15	133	-	133
1986	3800	-	126	-	-	126	-	126
1987	2140	-	148	4	-	152	-	152
1988	2580	-	75	6	1	82	-	82
1989	2580	-	91	2	-	93	-	93
1990	2580	-	90	14	-	104	-	104
[1]1991	2580	-	81	586	140	804	-	804
1992	2580	-	63	1181	606	1850	-	1850
[2]1993	2650	-	431	1279	317	2044	-	2044
[3]1994	3100	-	8	2656	410	3074	-	3074
1995	3170	-	168	2265	715	3148	27	3175
1996	3170	-	55	2299	817	3171	187	3358
1997	3600	-	570	2422	583	3574	222	3797
1998	3800	-	562	2014	1223	3800	131	3931
1999	4800	200	717	1521	2464	4702	149	4851
2000	5300	200	473	1822	2940	5235	201	5436
2001	4700	300	692	1298	2515	4505	263	4768
2002	2700	300	261	1553	885	2699	244	2943
2003	2700	300	612	1623	373	2608	157	2765
2004	3300	200	2041	755	376	3172	96	3268
2005	4608	392	1190	1392	1054	3636	9	3645
2006	4608	392	846	1997	1111	3954	32	3986
2007	4820	200	267	2633	1678	4578	4	4582
2008	4912	100	349	2703	1265	4317	4	4321
2009	3475	25	298	2450	727	3475	2	3477
2010	4900	100	280	1846	2454	4580	1	4581
2011	4432	168	254	2340	1653	4247	111	4358
[4]2012	3864	336	151	2256	1110	3517	130	3647
[5]2012	3864	336	162	2469	1233	3864	336	4200

[1] Nordmøre separator grate introduced.
[2] Overall TAC not caught because TAC for SFAs 14 and 15 was exceeded.
[3] Individual SFA TACs combined.
[4] Current year to date (November 20, 2012).
[5] Current year prorated to total TAC.

Table 2. Number of active vessels and total licences (in brackets) for the eastern Scotian Shelf shrimp fishery.

	Trap	Trawl	
Year	Scotia-Fundy[1]	Scotia-Fundy[2]	Gulf[3]
1995	4	24(23)	6(23)
1996	9(17)	21(24)	6(23)
1997	10(17)	18(23)	6(23)
1998	15(26)	17(28)[4]	10(23)[5]
1999	15(22)	19(28)[4]	10(23)[5]
2000	12(21)	18(32)[6]	10(23)[5]
2001	10(28)	18(28)[4]	10(23)[5]
2002	10(14)[7]	15(23)	6(23)
2003	9(14)	14(23)	5(23)
2004	6(14)	14(23)	6(23)
2005	2(14)	20(28)[8]	7(24)[9]
2006	5(14)	18(28)	7(24)
2007	2(14)	20(28)	7(24)
2008	1(14)	18(28)	7(24)
2009	1(14)	17(28)	6(14)[10]
2010	3(14)	18(28)	7(14)
2011	7(14)	15(28)	5(14)
2012	8(14)	12(28)	5(14)

Notes:

[1] All but one active trap licences are vessels <45'. They receive about 8% of the TAC.
[2] These vessels receive about 70% of the TAC according to the management plan. Inactive NAFO 4X licences (15) not included in total.
[3] All licences 65-100' length over all (LOA). Eligibility to fish in Scotia-Fundy for about 23% of the TAC.
[4] Temporary allocation divided among 5 vessels.
[5] Temporary allocation divided among 4 vessels.
[6] Temporary allocation divided among 9 licences.
[7] Nine (9) licences were made permanent for 2002. The reduction in the total number of trap licences is due to cancellation of some non-active exploratory licences.
[8] Five (5) temporary licences made permanent.
[9] One (1) temporary licence made permanent.
[10] The previously reported number of licenses included (10) that were invalid for a number of reasons. The number of valid licenses was updated in 2009.

Table 3. Input data for traffic light analysis

Indicators	RV_CPUE	G_CPUE	St_CPUE	RV_CV	Comm_area	RVSSB	BB_1	RV_2	RV_4	sex_mm	max_mm	pred	count	Exp_tot	Exp_fem	fem_prop	fem_size	pop_even	Rvtemp	Spring SST	capelin	Cod_R	G_halibut	snow_c
Action	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile	Pctile
Indirect																								
Rule	Abundance (Production == red) +																							
Direct																								
Overwts	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Maxwts	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Level_YG	0.66	0.66	0.66	0.33	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.33	0.33	0.33	0.33	0.66	0.66	0.66	0.33	0.33	0.66	0.33	0.66	0.66
Level_RY	0.33	0.33	0.33	0.66	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.66	0.66	0.66	0.66	0.33	0.33	0.33	0.66	0.66	0.33	0.66	0.33	0.33
Characteristics	Polarity																							
Abundance	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Production	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
FishingM	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0
Ecosystem	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1

Year	RV_CPUE	G_CPUE	St_CPUE	RV_CV	Comm_area	RVSSB	BB_1	RV_2	RV_4	sex_mm	max_mm	pred	count	Exp_tot	Exp_fem	fem_prop	fem_size	pop_even	Rvtemp	Spring SST	capelin	Cod_R	G_halibut	snow_c
1982	34.50	128.00	NAN	89.06	NAN	5040.65	NAN	NAN	NAN	21.46	28.24	179.29	NAN	NAN	NAN	NAN	NAN	0.81	NAN	NAN	NAN	2.38	0.00	NAN
1983	71.50	127.70	NAN	78.52	NAN	7323.05	NAN	NAN	NAN	21.80	28.03	164.05	NAN	NAN	NAN	NAN	NAN	0.77	NAN	2.78	NAN	2.42	0.00	NAN
1984	39.00	109.50	NAN	75.84	NAN	4460.96	NAN	NAN	NAN	22.17	27.69	353.25	NAN	NAN	NAN	NAN	NAN	0.73	NAN	0.48	NAN	5.57	0.06	NAN
1985	17.00	75.40	NAN	83.09	NAN	2417.71	NAN	NAN	NAN	21.77	27.87	236.37	NAN	NAN	NAN	NAN	NAN	0.75	NAN	-0.07	1.55	1.71	0.05	NAN
1986	23.00	87.30	NAN	106.13	NAN	3187.87	NAN	NAN	NAN	23.63	27.94	144.33	NAN	NAN	NAN	NAN	NAN	0.74	NAN	-0.77	0.13	0.37	0.09	NAN
1987	25.50	90.70	NAN	67.53	NAN	3424.46	NAN	NAN	NAN	23.16	27.94	187.04	NAN	NAN	NAN	NAN	NAN	0.79	NAN	-1.32	0.77	0.87	0.16	NAN
1988	31.50	85.10	NAN	60.14	NAN	4047.02	NAN	NAN	NAN	23.84	28.12	142.81	NAN	NAN	NAN	NAN	NAN	0.76	NAN	-0.92	0.17	1.19	0.06	NAN
1989	NAN	133.40	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	66.58	NAN	NAN	NAN	NAN	NAN	NAN	NAN	-1.07	18.38	1.75	0.00	NAN
1990	NAN	134.50	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	67.33	NAN	NAN	NAN	NAN	NAN	NAN	NAN	-1.02	9.23	1.16	0.00	NAN
1991	NAN	197.90	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	46.91	NAN	NAN	NAN	NAN	NAN	NAN	NAN	-0.77	5.07	0.17	0.46	NAN
1992	NAN	176.30	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	32.10	NAN	NAN	NAN	NAN	NAN	NAN	NAN	-1.72	34.88	0.17	0.08	NAN
1993	75.00	187.89	142.20	80.33	31.00	NAN	NAN	NAN	NAN	23.78	30.45	68.53	NAN	NAN	NAN	NAN	NAN	NAN	NAN	-2.07	193.36	0.29	1.86	NAN
1994	NAN	213.52	188.40	NAN	48.00	NAN	NAN	NAN	NAN	NAN	NAN	66.17	NAN	NAN	NAN	0.89	26.05	NAN	NAN	-1.52	1563.89	0.30	1.98	NAN
1995	173.02	187.02	181.17	82.84	71.00	10912.15	NAN	358.50	875.92	24.05	29.27	66.52	55.92	13.44	21.04	0.72	26.03	0.83	1.59	-1.17	138.62	0.54	1.74	NAN
1996	213.92	244.58	224.35	64.88	99.00	13368.38	NAN	307.34	1247.63	24.73	29.99	32.56	54.47	11.50	16.11	0.68	26.01	0.83	1.72	-0.92	87.53	0.16	4.78	NAN
1997	193.00	236.26	218.89	53.46	146.00	12100.80	NAN	128.85	1257.47	24.94	29.78	35.85	56.35	14.41	19.08	0.84	26.44	0.80	2.74	-0.47	146.64	0.40	2.91	6588.78
1998	238.38	343.73	298.94	74.42	209.00	15707.48	NAN	39.89	1883.71	24.33	29.51	59.87	53.22	12.08	14.73	0.60	25.68	0.78	1.97	-0.06	284.31	0.31	0.41	8446.24
1999	268.40	395.70	325.53	72.20	258.00	17607.48	NAN	165.63	3010.18	24.08	29.31	64.13	55.30	13.24	16.90	0.63	25.46	0.75	3.24	-0.50	159.96	1.39	1.67	10482.22
2000	233.36	383.66	365.48	72.00	242.00	15893.36	NAN	280.34	0.00	24.74	29.74	76.29	55.19	17.06	19.79	0.58	25.57	0.78	3.60	0.07	32.38	0.79	11.44	5128.69
2001	183.32	428.24	443.46	126.03	221.00	14475.58	NAN	174.90	1184.11	24.29	29.19	73.28	54.70	19.05	19.56	0.63	25.15	0.79	2.36	-0.55	15.99	1.58	3.66	4664.29
2002	161.40	572.36	523.48	111.15	192.00	14133.20	980.00	134.00	399.17	24.45	29.02	57.30	52.53	14.17	13.43	0.70	25.61	0.78	2.77	-0.09	49.85	0.32	3.88	2212.31
2003	204.42	675.41	520.72	104.48	265.00	16916.16	196.00	576.74	1411.07	24.31	29.05	100.65	53.48	9.83	10.91	0.73	25.68	0.84	2.69	-1.30	2.70	1.03	6.69	1656.46
2004	353.70	793.14	549.32	78.00	263.00	26856.47	316.00	354.09	839.46	24.13	29.44	57.46	54.96	6.75	9.48	0.80	25.41	0.80	1.99	-0.43	5.93	0.64	3.44	1248.30
2005	312.90	683.25	496.53	83.01	364.00	18587.50	198.00	187.02	4502.48	23.63	29.46	99.05	58.93	8.20	13.05	0.66	25.72	0.73	2.41	0.47	99.41	0.25	14.00	1500.56
2006	275.20	716.40	614.86	75.86	296.00	16288.53	61.00	121.30	0.00	23.39	29.35	77.47	63.23	10.55	13.57	0.55	25.96	0.75	3.62	1.03	5.78	0.80	18.92	3012.34
2007	281.20	696.62	507.79	66.34	389.00	18345.54	194.00	39.00	0.00	23.67	29.07	51.64	65.30	11.92	12.28	0.45	25.70	0.73	2.30	-0.73	8.45	0.29	7.77	5482.42
2008	226.10	664.07	520.17	72.25	423.00	12119.42	484.11	134.72	1046.18	23.84	28.57	92.82	61.52	13.98	20.50	0.52	24.98	0.73	1.96	0.03	1.36	1.24	6.51	6145.07
2009	333.10	648.76	628.16	91.70	324.00	24853.59	566.52	304.05	463.00	24.21	28.74	55.35	57.56	7.65	9.37	0.72	25.06	0.77	2.59	-0.61	0.21	0.57	5.42	4424.86
2010	273.00	536.23	465.57	105.47	350.00	21706.69	205.08	188.00	1036.00	24.53	28.87	70.88	57.77	12.31	15.45	0.74	25.20	0.80	2.35	1.54	11.06	0.16	2.55	6264.81
2011	223.60	671.18	456.36	78.89	320.00	16823.67	97.34	85.22	1044.08	24.27	28.51	149.12	61.34	14.28	18.61	0.71	25.19	0.77	2.99	0.72	0.57	0.93	1.96	4912.83
2012	**205.30**	**552.28**	**496.05**	**66.78**	**294.00**	**14762.95**	**124.76**	**273.22**	**975.52**	**23.88**	**29.01**	**31.80**	**59.61**	**15.01**	**18.93**	**0.72**	**25.22**	**0.79**	**4.20**	**0.43**	**1.25**	**0.65**	**1.37**	**4436.99**

Note: NAN = not a number.

Table 4. Set statistics from DFO-industry survey CK1201 conducted by MV Cody & Kathryn from 1-13 June 2012.

SET	SFA	DATE	LAT.	LONG.	SPEED (kts)	DIST. (n.m.)	DUR. (min)	WING. (m)	DEPTH (fth)	TEMP (°C)	RAW CATCH (kg)	STAND. CATCH (kg)	DENSITY (gm/m2 or m.t./km2)
1	15	01-Jun-2012	452209	595575	2.48	1.20	0.02	15.83	80.76	3.20	176.45	201.33	5.00
2	15	01-Jun-2012	451758	595454	2.51	1.20	0.02	15.68	82.89	3.30	257.64	297.53	7.39
3	15	01-Jun-2012	451928	594442	2.48	1.21	0.02	15.61	70.10	3.21	148.33	170.73	4.24
4	15	01-Jun-2012	452663	594317	2.48	1.25	0.02	15.50	74.36	3.10	21.77	24.52	0.61
8	15	01-Jun-2012	453066	594524	2.34	1.23	0.02	15.70	78.63	3.43	119.75	135.40	3.36
9	15	01-Jun-2012	453871	595100	2.70	1.28	0.02	15.54	80.76	3.28	213.64	233.21	5.79
10	15	01-Jun-2012	452989	595873	2.38	1.18	0.02	16.15	82.89	3.20	136.99	155.74	3.87
12	15	01-Jun-2012	453359	600707	2.39	1.22	0.02	15.44	91.37	3.25	178.26	205.39	5.10
13	15	01-Jun-2012	453279	601111	2.28	1.10	0.02	16.32	112.64	3.27	186.88	227.20	5.64
14	15	02-Jun-2012	452240	610128	2.46	1.22	0.02	14.60	57.36	2.83	116.12	142.00	3.53
15	15	02-Jun-2012	452555	605196	2.52	1.27	0.02	14.89	63.76	3.03	231.33	265.63	6.59
18	17	02-Jun-2012	452735	604542	2.51	1.17	0.02	15.60	74.36	3.10	194.59	232.15	5.76
20	17	02-Jun-2012	453310	602927	2.38	1.45	0.02	15.79	91.37	3.22	153.32	145.63	3.62
21	17	02-Jun-2012	452797	603102	2.52	1.29	0.02	15.85	84.97	3.20	300.28	318.35	7.90
22	17	02-Jun-2012	451582	602389	2.46	1.22	0.02	15.75	87.11	3.20	124.74	140.66	3.49
24	17	02-Jun-2012	445830	602853	2.33	1.12	0.02	16.23	110.51	4.07	119.75	143.30	3.56
25	13	02-Jun-2012	445337	602467	2.47	1.22	0.02	16.25	131.72	3.78	81.19	88.94	2.21
26	13	03-Jun-2012	445396	603598	2.75	1.31	0.02	16.42	125.38	6.13	146.97	149.16	3.70
27	13	03-Jun-2012	445100	603994	2.18	1.10	0.02	15.50	142.39	6.39	88.91	113.21	2.81
28	13	03-Jun-2012	445105	604507	2.42	1.24	0.02	15.47	140.25	6.80	135.63	153.52	3.81
29	13	03-Jun-2012	445355	604945	2.48	1.23	0.02	15.12	101.98	6.69	95.71	112.11	2.78
30	13	03-Jun-2012	444961	605465	2.37	1.42	0.02	15.79	123.25	6.92	243.13	235.88	5.86
31	13	03-Jun-2012	445444	605713	2.41	1.26	0.02	15.68	112.64	6.85	180.08	198.88	4.94
32	13	03-Jun-2012	445811	605790	2.49	1.35	0.02	15.38	99.85	6.62	93.44	98.03	2.43
33	13	03-Jun-2012	445465	610093	2.39	1.20	0.02	15.94	118.98	6.80	297.56	339.25	8.42
34	13	03-Jun-2012	445305	610948	2.47	1.21	0.02	15.26	97.77	6.74	196.86	231.29	5.74
35	13	07-Jun-2012	453590	590628	2.23	0.96	0.02	16.64	118.98	4.48	76.20	104.00	2.58
36	13	07-Jun-2012	453933	590000	2.56	1.28	0.02	16.64	114.72	4.49	73.94	75.32	1.87
37	13	07-Jun-2012	453830	585393	2.92	1.24	0.02	16.29	116.85	4.50	51.26	55.37	1.37
38	13	07-Jun-2012	454090	584827	2.52	1.12	0.02	16.93	121.12	4.55	190.51	218.14	5.42
39	13	07-Jun-2012	453255	584538	2.79	1.27	0.02	17.32	108.38	4.15	70.31	69.48	1.72
40	14	07-Jun-2012	453174	583616	2.42	1.11	0.02	17.05	140.25	4.20	168.74	194.15	4.82
41	14	08-Jun-2012	454950	584914	2.26	1.11	0.02	16.06	138.12	4.60	536.97	657.16	16.31
42	14	08-Jun-2012	455052	584393	2.36	1.15	0.02	16.00	131.72	4.59	117.48	138.35	3.43
43	14	08-Jun-2012	455048	583687	2.42	1.19	0.02	15.82	146.60	4.62	291.48	338.14	8.39
44	14	09-Jun-2012	454762	583075	2.67	1.28	0.02	16.66	157.26	4.60	68.49	69.88	1.73
45	14	09-Jun-2012	454282	582221	2.42	1.20	0.02	15.77	133.86	4.12	55.34	63.36	1.57
46	14	09-Jun-2012	454296	581440	2.54	1.24	0.02	15.78	123.25	4.03	99.79	111.35	2.76
47	17	09-Jun-2012	453922	582200	2.38	1.14	0.02	16.47	178.48	4.20	38.10	43.99	1.09
48	17	09-Jun-2012	453776	583006	2.52	1.22	0.02	17.08	125.38	4.11	75.75	79.16	1.97
52	17	09-Jun-2012	453404	582066	2.06	1.07	0.02	16.05	193.35	4.19	42.64	54.11	1.34
54	17	10-Jun-2012	445048	583251	2.74	1.31	0.02	16.44	127.51	3.10	371.95	376.04	9.34
55	17	10-Jun-2012	445549	582056	2.77	1.26	0.02	16.64	135.99	3.20	555.02	576.29	14.31
56	17	10-Jun-2012	445537	584344	2.39	0.98	0.02	16.16	138.12	2.70	285.77	393.03	9.76
57	17	11-Jun-2012	445444	601803	2.67	1.26	0.02	16.20	116.85	3.61	89.81	95.55	2.37
58	17	11-Jun-2012	445147	601672	2.75	1.34	0.02	16.35	129.59	3.66	100.70	99.97	2.48
59	17	11-Jun-2012	443704	601417	2.86	1.28	0.02	15.67	108.38	4.63	88.91	96.74	2.40
60	17	11-Jun-2012	444149	600047	2.25	1.14	0.02	16.08	110.51	4.32	88.91	105.51	2.62
61	15	11-Jun-2012	444755	595829	2.54	1.15	0.02	16.59	129.59	4.23	136.08	154.60	3.84
62	15	11-Jun-2012	445368	595866	2.56	1.22	0.02	16.12	101.98	3.96	112.95	125.29	3.11
63	15	11-Jun-2012	445183	594323	2.28	1.08	0.02	16.51	118.98	3.95	159.67	195.38	4.85
64	14	12-Jun-2012	443885	590295	2.35	1.12	0.02	16.92	121.12	2.99	228.79	262.73	6.52
65	14	12-Jun-2012	444718	585393	2.23	1.14	0.02	16.96	138.12	2.95	381.02	427.45	10.61
66	14	12-Jun-2012	444776	583980	2.32	1.14	0.02	16.82	125.38	3.10	175.72	200.00	4.97
67	14	12-Jun-2012	445143	590313	2.43	1.25	0.02	16.41	127.51	2.92	459.58	488.47	12.13
68	14	12-Jun-2012	444688	591103	2.49	1.21	0.02	17.00	118.98	3.00	332.03	351.33	8.72
69	14	12-Jun-2012	445083	592792	2.52	1.16	0.02	16.50	131.72	3.77	435.00	493.83	12.26
70	14	13-Jun-2012	444150	593582	2.40	1.17	0.02	17.25	106.24	4.04	341.10	366.98	9.11
71	14	13-Jun-2012	444215	594656	2.23	1.17	0.02	16.49	133.86	4.20	173.27	195.57	4.86
74	15	13-Jun-2012	450239	605451	2.42	1.20	0.02	16.89	104.11	5.85	151.96	163.51	4.06

Table 5. Minimum survey population numbers at age from modal analysis. Numbers x 10^6.

Age	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
1[1]	-	-	-	-	-	-	-	980	196	316	198	61	194	484	567	263	97	125	316
2	359	307	129	40	166	280	175	134	616	354	187	121	39	114	304	188	85	273	215
3	1046	276	1159	785	27	757	362	383	312	3118	652	880	506	396	267	1020	752	879	754
4	876	1248	1257	1884	3010	0[3]	1184	399	1506	839	4502	0[4]	0[4]	1190	463	1036	1044	976	1428
5+	1702	2162	1539	2047	1952	3374	2110	1847	1727	3324	2224	5106	5506	3017	6020	4109	2488	1791	2891
TOTAL	3983	3993	4084	4755	5155	4412	3831	2763	4161	7636	7763	6169	6244	5201	7622	6616	4467	4044	5161
Age 4+ males[2]	1369	1971	1578	2243	3235	1784	1771	938	1526	1549	4956	3916	2804	3317	4263	3454	1755	1208	2424
Primiparous[3]	649	777	709	889	736	728	817	678	551	870	786	771	1739	892	1492	1324	930	279	868
Multiparous	560	661	509	647	991	863	706	630	1188	1698	1183	480	1157	482	1295	630	945	1405	890
Total females	1209	1438	1218	1535	1727	1591	1523	1308	1739	2568	1969	1251	2896	1374	2787	1954	1875	1684	1758

Notes:

[1] Belly-bag.
[2] Total population less ages 2,3 males, transitionals and females, i.e. males that will potentially change to females the following year.
[3] Includes transitionals.
[4] Four year olds of the 1996 and 2002, 2003 year classes were not distinguishable in the MIX analysis. These year classes appear to be small and are contained in the ages 3 or 5+ categories.

Table 6. Survey biomasses, commercial shrimp catches, and exploitation rates (catch/biomass) by survey strata (13-15, offshore part), and the inshore area (17), 1995-2012.

	SFA	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Mean
Biomass (mt)	13	4838	6838	5921	7188	9517	5866	4089	3114	7047	12184	9687	6129	7507	4144	6208	2688	4537	6011	6324
	14	9068	12094	9472	11279	11040	9364	12325	12020	12035	20228	20035	18929	15957	12710	20544	16009	14614	10941	13984
	15	5300	6610	4737	4549	7807	7268	2073	2766	3751	4399	4378	5130	5345	4227	7235	4784	4223	4232	4975
	17	4415	3663	6221	9530	8262	9365	6541	2872	5296	11627	10333	7581	9622	9823	11438	13731	7136	6793	8086
	Total	**23621**	**29205**	**26351**	**32546**	**36626**	**31863**	**25028**	**20773**	**28130**	**48438**	**44433**	**37769**	**38431**	**30904**	**45424**	**37212**	**30510**	**27978**	**33069**
Catch (mt)	13	119	19	549	517	616	233	432	253	585	2011	1145	630	85	212	11	125	4	0	444
	14	2288	2297	2349	2029	1516	1750	1206	1552	1621	752	1372	1998	2640	2696	2026	1844	2309	2691	1897
	15	752	862	649	486	442	915	965	264	226	338	613	444	612	534	540	1123	982	890	632
	17	16	180	251	899	2276	2538	2165	874	333	168	515	915	1245	879	900	1490	1062	619	983
	Total	**3175**	**3358**	**3797**	**3931**	**4851**	**5436**	**4768**	**2943**	**2765**	**3268**	**3645**	**3986**	**4582**	**4321**	**3477**	**4581**	**4358**	**4200**	**3955**
Exploitation (%)	13	2.5	0.3	9.3	7.2	6.5	4.0	10.6	8.1	8.3	16.5	11.8	10.3	1.1	5.1	0.2	4.6	0.1	0.0	6.8
	14	25.2	19.0	24.8	18.0	13.7	18.7	9.8	12.9	13.5	3.7	6.8	10.6	16.5	21.2	9.9	11.5	15.8	24.6	15.0
	15	14.2	13.0	13.7	10.7	5.7	12.6	46.6	9.6	6.0	7.7	14.0	8.6	11.5	12.6	7.5	23.5	23.3	21.0	12.9
	17	0.4	4.9	4.0	9.4	27.5	27.1	33.1	30.4	6.3	1.4	5.0	12.1	12.9	8.9	7.9	10.9	14.9	9.1	12.8
	Total	**13.4**	**11.5**	**14.4**	**12.1**	**13.2**	**17.1**	**19.1**	**14.2**	**9.8**	**6.7**	**8.2**	**10.6**	**11.9**	**14.0**	**7.7**	**12.3**	**14.3**	**15.0**	**12.4**

Table 7. Fish bycatch of the commercial shrimp fishery by strata (14, 15, inshore-17), but fleet and by season from observer data of 55 sets from 2012.

SPECIES	TOTAL BYCATCH		BYCATCH BY AREA			BYCATCH BY FLEET	
	Est Weight (Kgs)	TOTAL %	SFA 14	SFA 15	SFA 17	GULF	SCOTIA-FUNDY
PANDALUS BOREALIS	108174	98.44%	99.54%	96.87%	98.60%	99.56%	97.27%
SILVER HAKE	535	0.49%	0.04%	1.35%	0.02%	0.04%	0.96%
HERRING (ATLANTIC)	261	0.24%	0.13%	0.42%	0.18%	0.13%	0.35%
WITCH FLOUNDER	190	0.17%	0.04%	0.39%	0.11%	0.04%	0.32%
LONGFIN SQUID, LONGFIN INSHORE SQUID	168	0.15%	-	-	0.79%	-	0.31%
AMERICAN PLAICE	162	0.15%	0.01%	0.33%	0.15%	0.01%	0.29%
EELPOUTS (NS)	100	0.09%	0.01%	0.24%	0.03%	0.01%	0.18%
ROCKLING UNIDENTIFIED	58	0.05%	-	0.15%	-	-	0.11%
CAPELIN	49	0.04%	0.08%	0.02%	-	0.08%	0.01%
REDFISH UNSEPARATED	41	0.04%	0.03%	0.06%	0.00%	0.03%	0.04%
TURBOT,GREENLAND HALIBUT	28	0.03%	0.01%	0.06%		0.01%	0.04%
ALEWIFE	39	0.04%	0.02%	0.02%	0.09%	0.02%	0.05%
SKATE (NS)	37	0.03%	0.07%	0.01%	-	0.07%	-
SEA CUCUMBERS	23	0.02%	-	0.06%	-		0.04%
SNOW CRAB (QUEEN)	7	0.01%	0.01%	0.00%	-	0.01%	0.00%
SQUIRREL OR RED HAKE	5	0.00%	-	0.01%	-	-	0.01%
COD (ATLANTIC)	4	0.00%	-	0.01%	-	-	0.01%
ARISTOSTOMIAS POLYDACTYLUS	2	0.00%	-	0.01%	-	-	0.00%
ATLANTIC SEA POACHER	2	0.00%	-		0.01%	-	0.00%
ATLANTIC WOLFFISH	1	0.00%	0.00%	-	-	0.00%	-
HADDOCK	1	0.00%	0.00%	-	-	0.00%	-
MACKEREL(ATLANTIC)	1	0.00%	0.00%	-	-	0.00%	-
SCULPINS	1	0.00%	0.00%	-	-	0.00%	-
NORTHERN SHORTFIN SQUID	1	0.00%	0.00%	-	-	0.00%	-
% BYCATCH		1.56%	0.46%	3.13%	1.40%	0.44%	2.73%

Note: Weights may be overestimated due to data collection restrictions (minimum recorded weight is 1 kg).

FIGURES

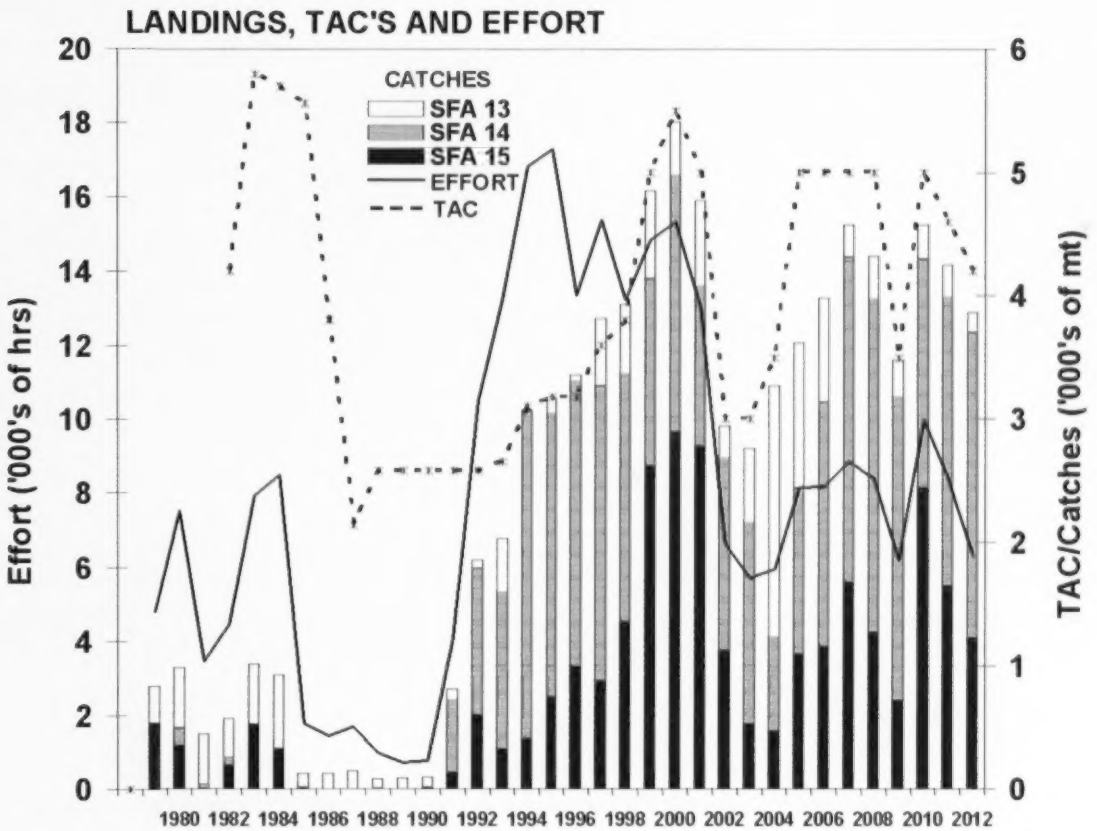


Figure 1. History of eastern Scotian Shelf shrimp fishery catches per SFA (13, 15 and 15), TAC (thousands of mt) and effort (thousands of hours), from 1980-2012.

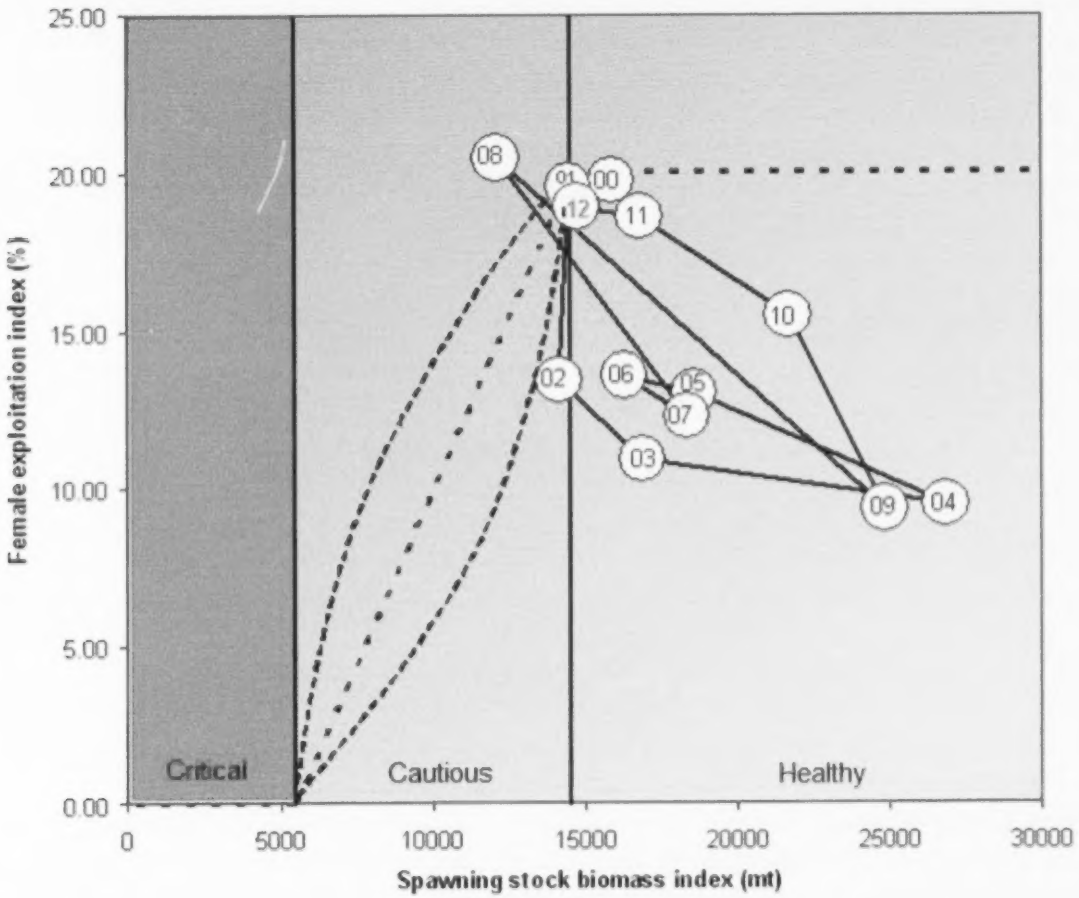


Figure 2. Graphical representation of the precautionary approach for Scotian Shelf shrimp. The dotted lines in the cautious zone represent a range of management actions possible, depending on whether the stock is stable, increasing or decreasing, or on trends in other indicators of stock or ecosystem health.

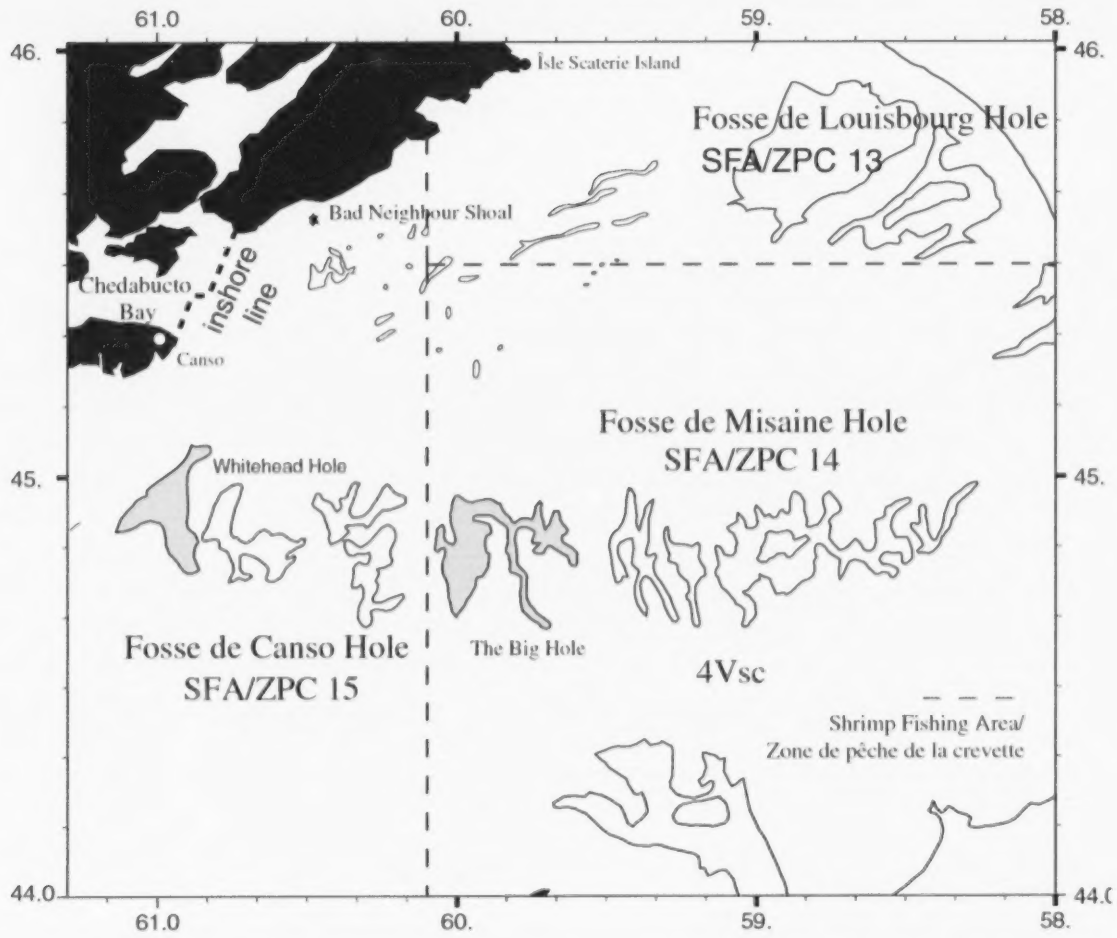


Figure 3. Shrimp Fishing Areas (SFAs) on the eastern Scotian Shelf. The inshore line prohibits trawlers from fishing inside Chedabucto Bay during the trapping season (fall to spring). Note the distinction between SFAs used to report catches and survey strata defined offshore (strata 13, 14, 15) by the 100 fathom contour (solid lines) and inshore (stratum 17) by the extent of LaHave clay north of 45°10' and west of 59°20' on surficial geology maps).

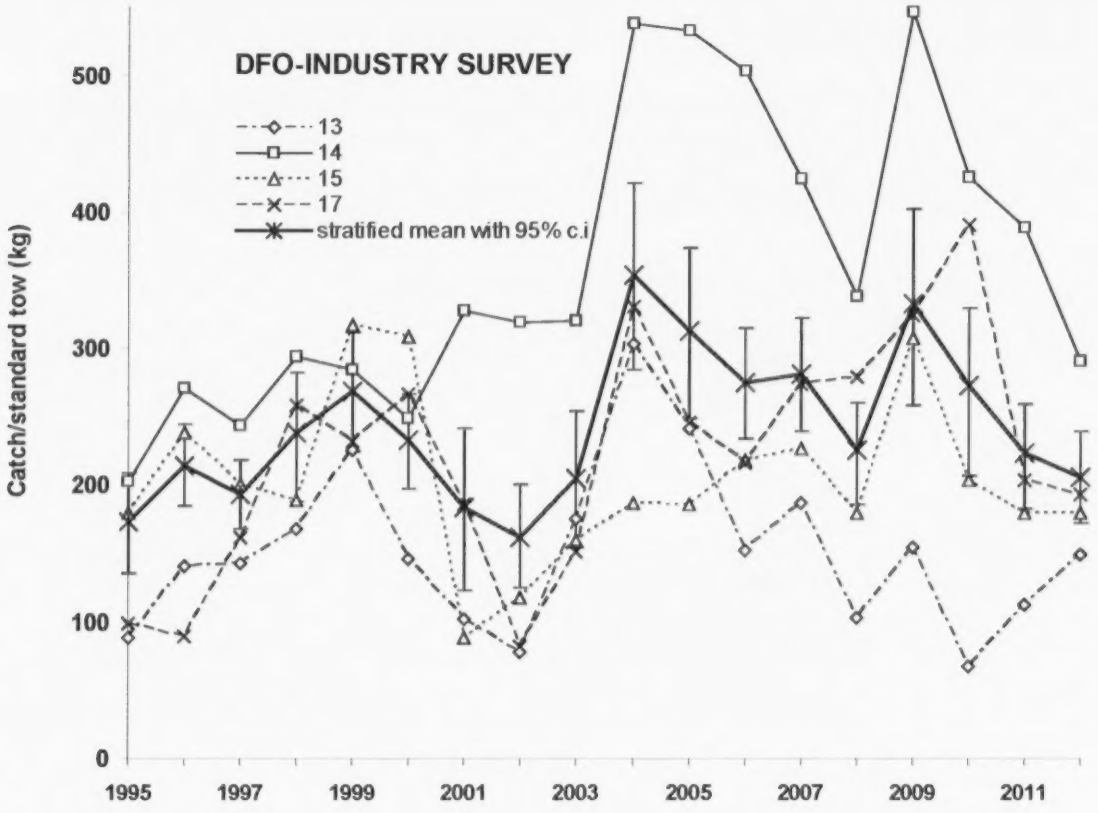


Figure 4. Stratified catch/standard tow for DFO-industry co-operative surveys from 1995-2012, and estimates for the individual strata, which approximately correspond to the main shrimp holes and SFAs. Stratum 13 - Louisbourg Hole and SFA 13; Stratum 14 - Misaine Holes and SFA 14; Stratum 15 - Canso Holes and the offshore part of SFA 15. The 'Inshore', or Stratum 17, is comprised of inshore parts of SFA 13-15.

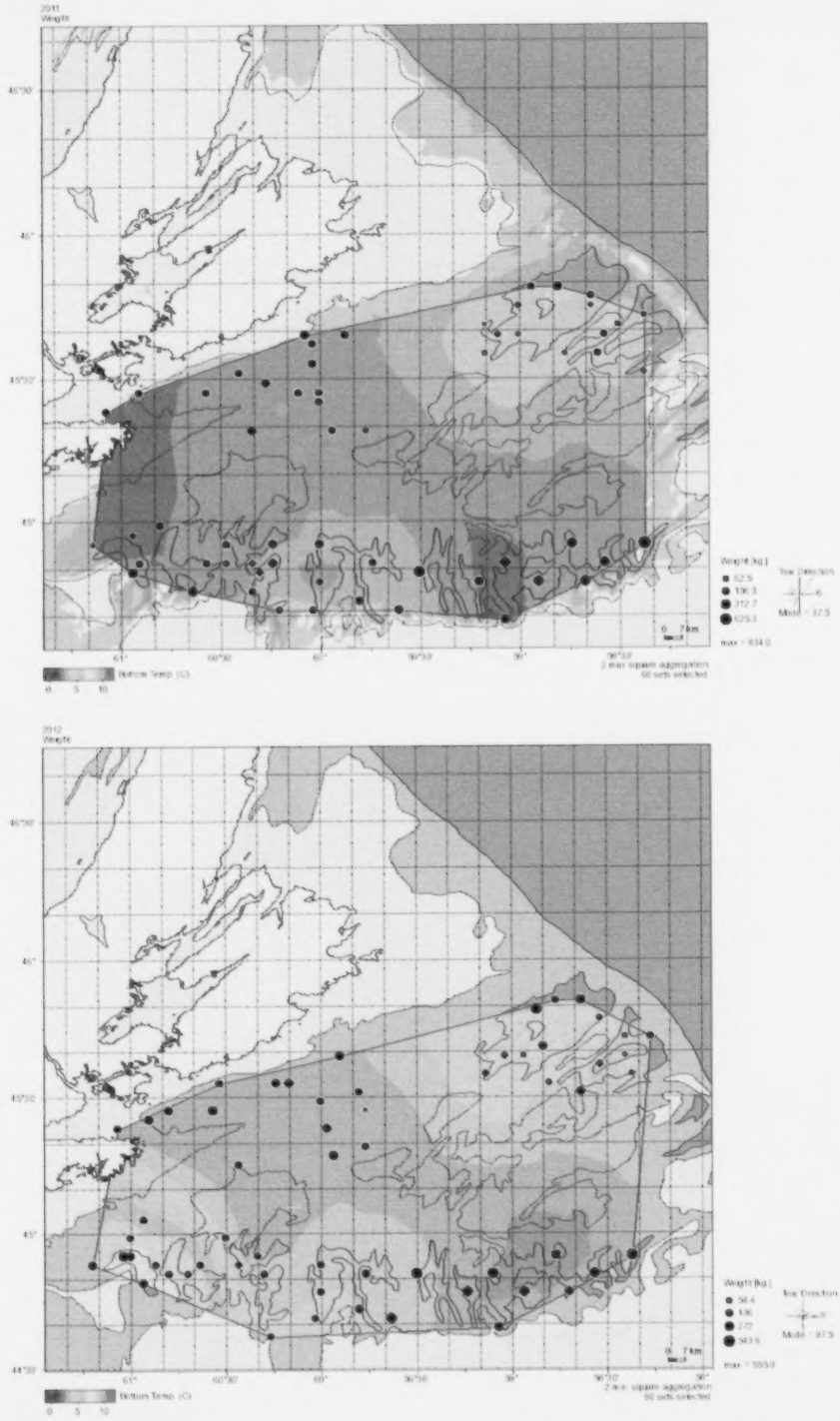


Figure 5. Distribution of catches (kg/standard 30 minute tow) and bottom temperatures from DFO-industry surveys 2011 and 2012. See previous research documents for distributions prior to 2011.

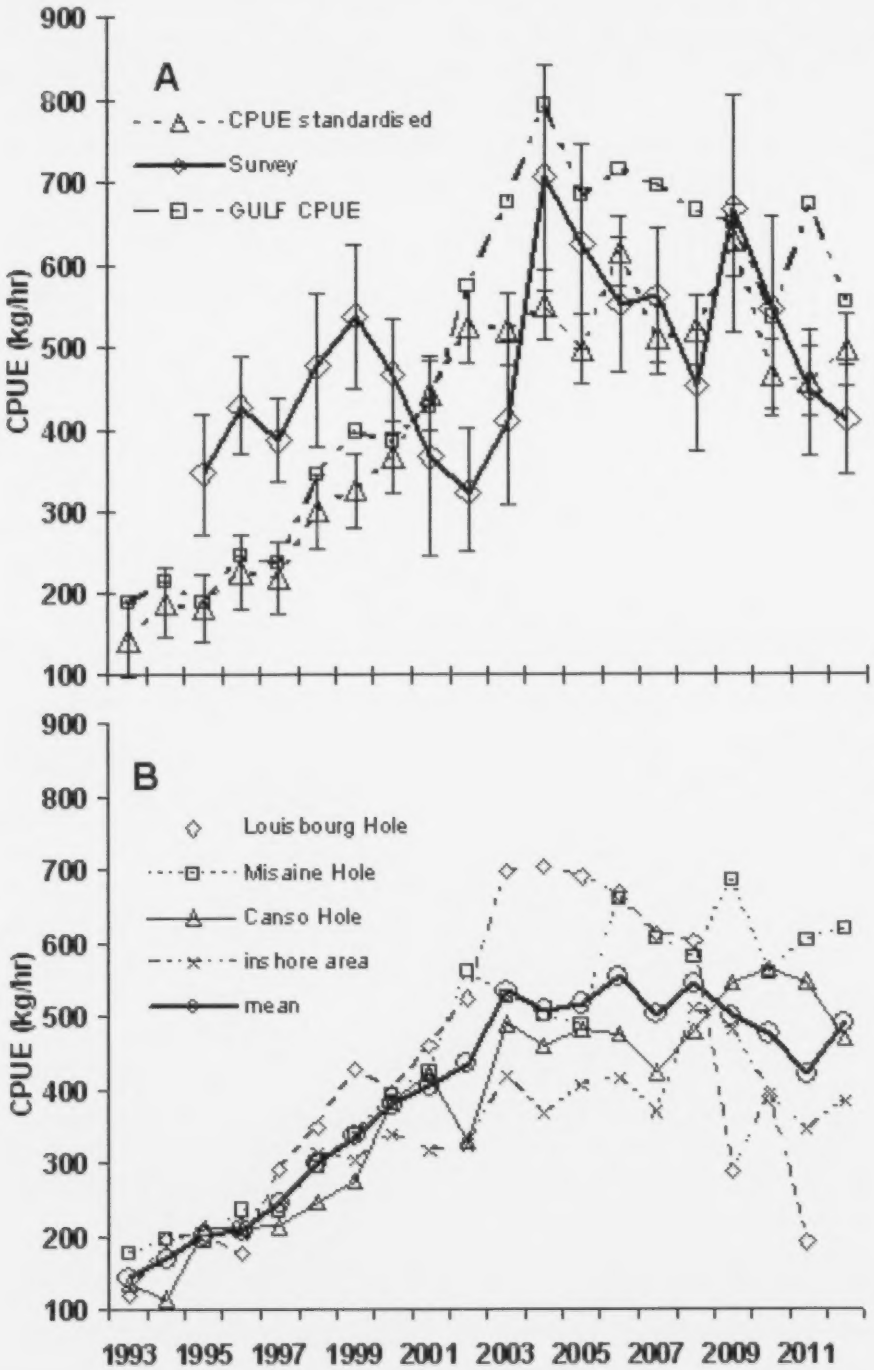


Figure 6. A - Survey stratified CPUE and, standardised commercial CPUE with 95% confidence intervals, and unstandardised Gulf vessel CPUE, and B - unstandardised commercial CPUE for each fishing area, from 1993-2012. Note that SFA 15 includes the inshore, but the latter is also shown separately since fishing began there in 1998.

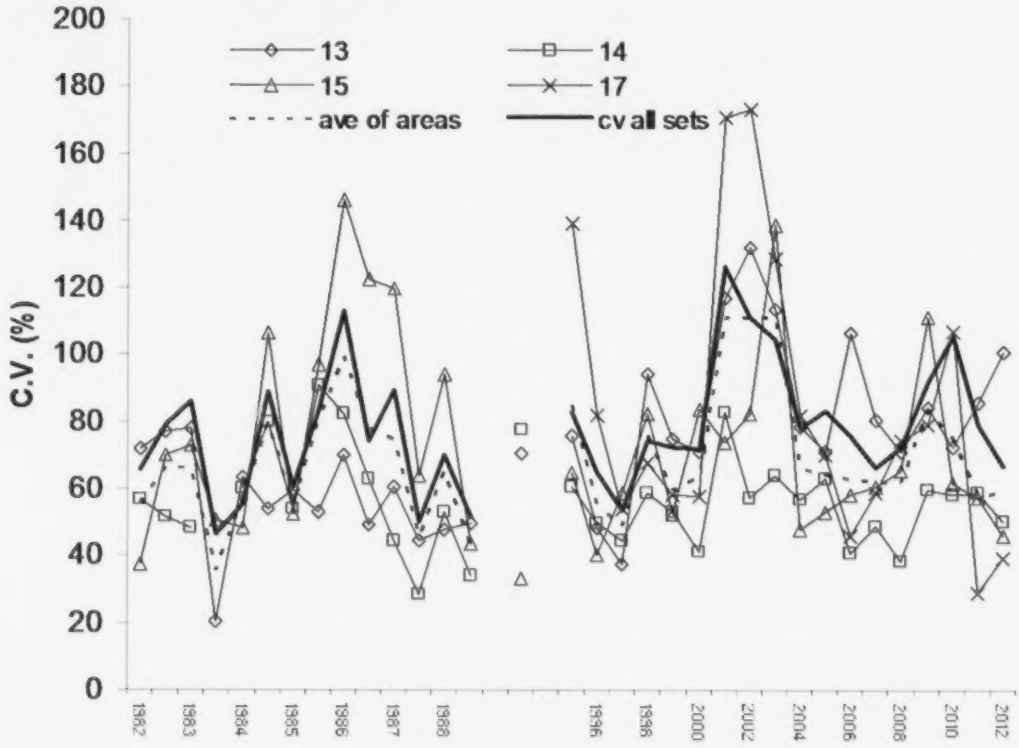


Figure 7. Coefficients of variation (CV) for shrimp survey strata 13, 14, 15, and 17, from 1992-2012. Note that the earlier survey series has two values per year, one for the spring and one for the fall survey. The use of fixed stations in 14 likely acts to constrain interannual changes in CV relative to other areas with random stations.

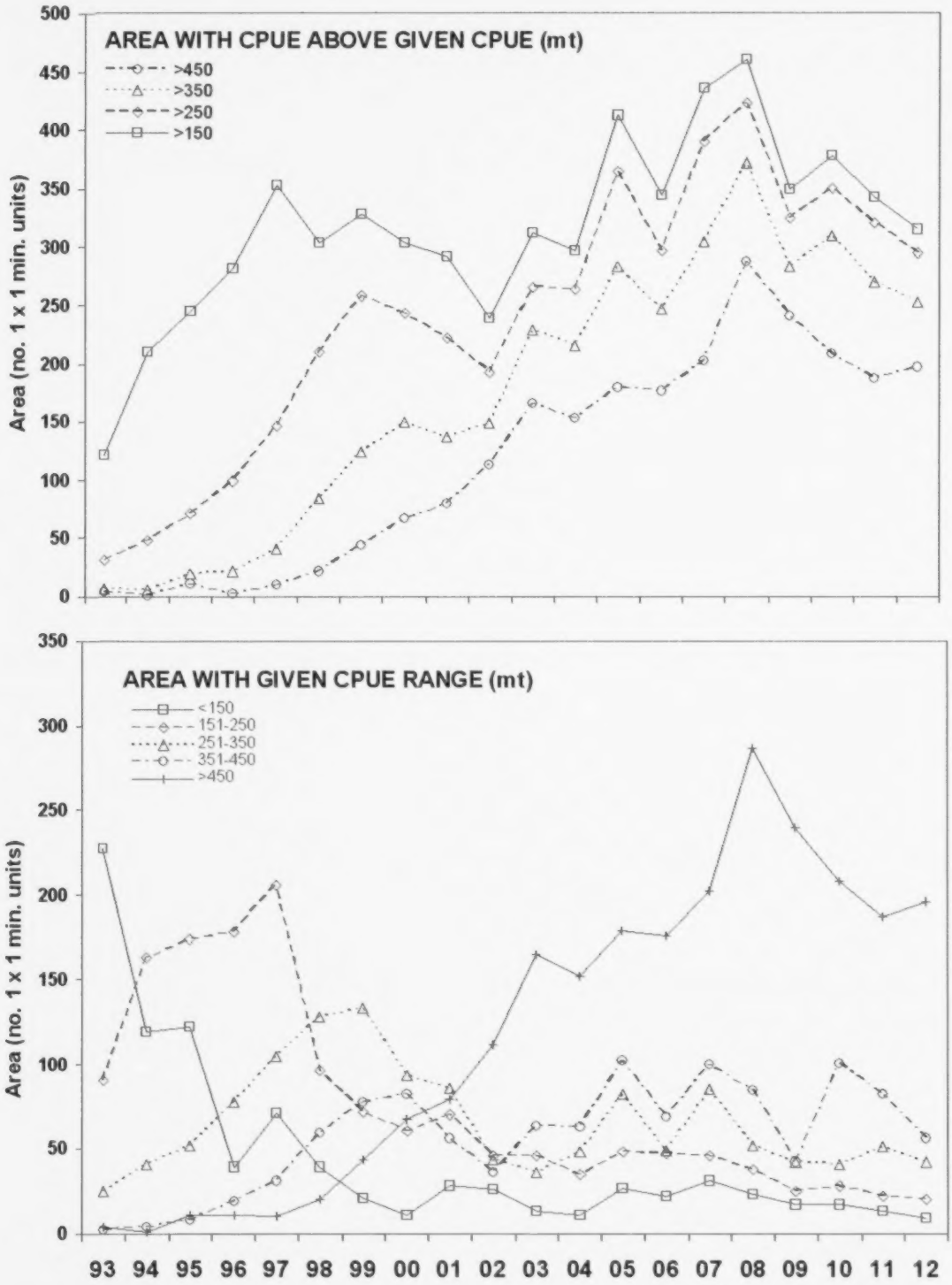


Figure 8. Number of 1 minute square unit areas fished by the shrimp fleet with mean catch rates above (top) and within (bottom) the values or ranges specified in the legend, from 1993-2012.

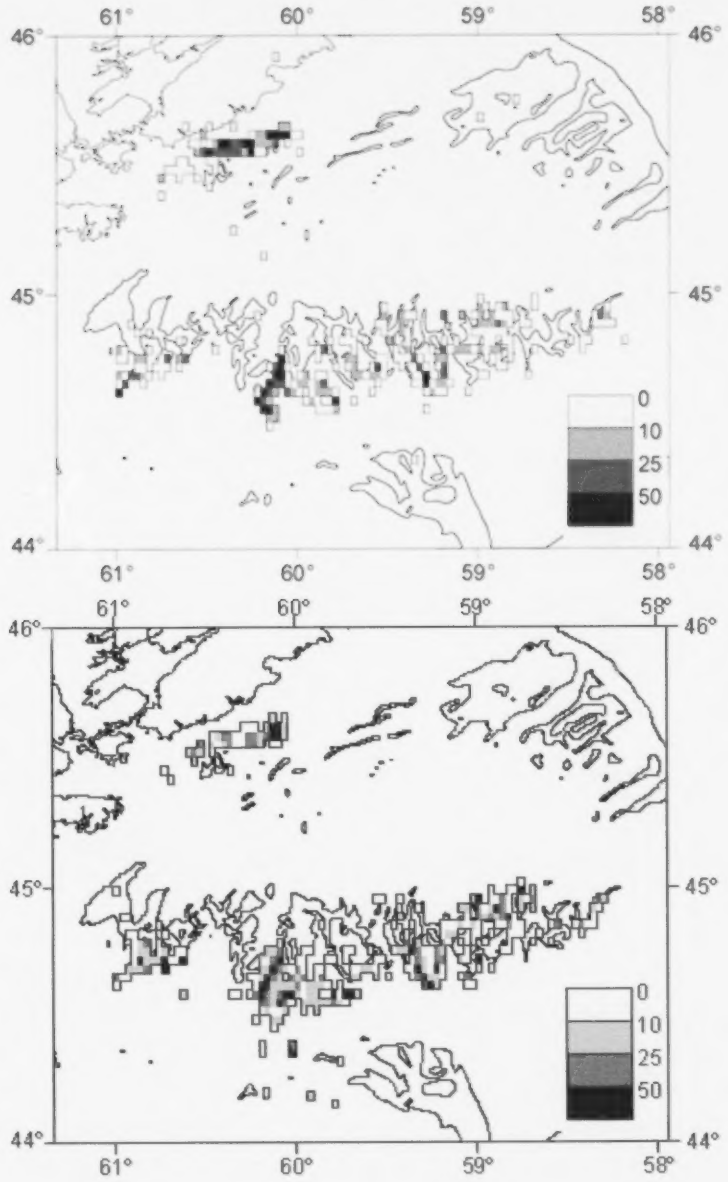


Figure 9. Annual effort by trawlers 2011 (top) and 2012 (bottom), cumulative by 1 minute squares.

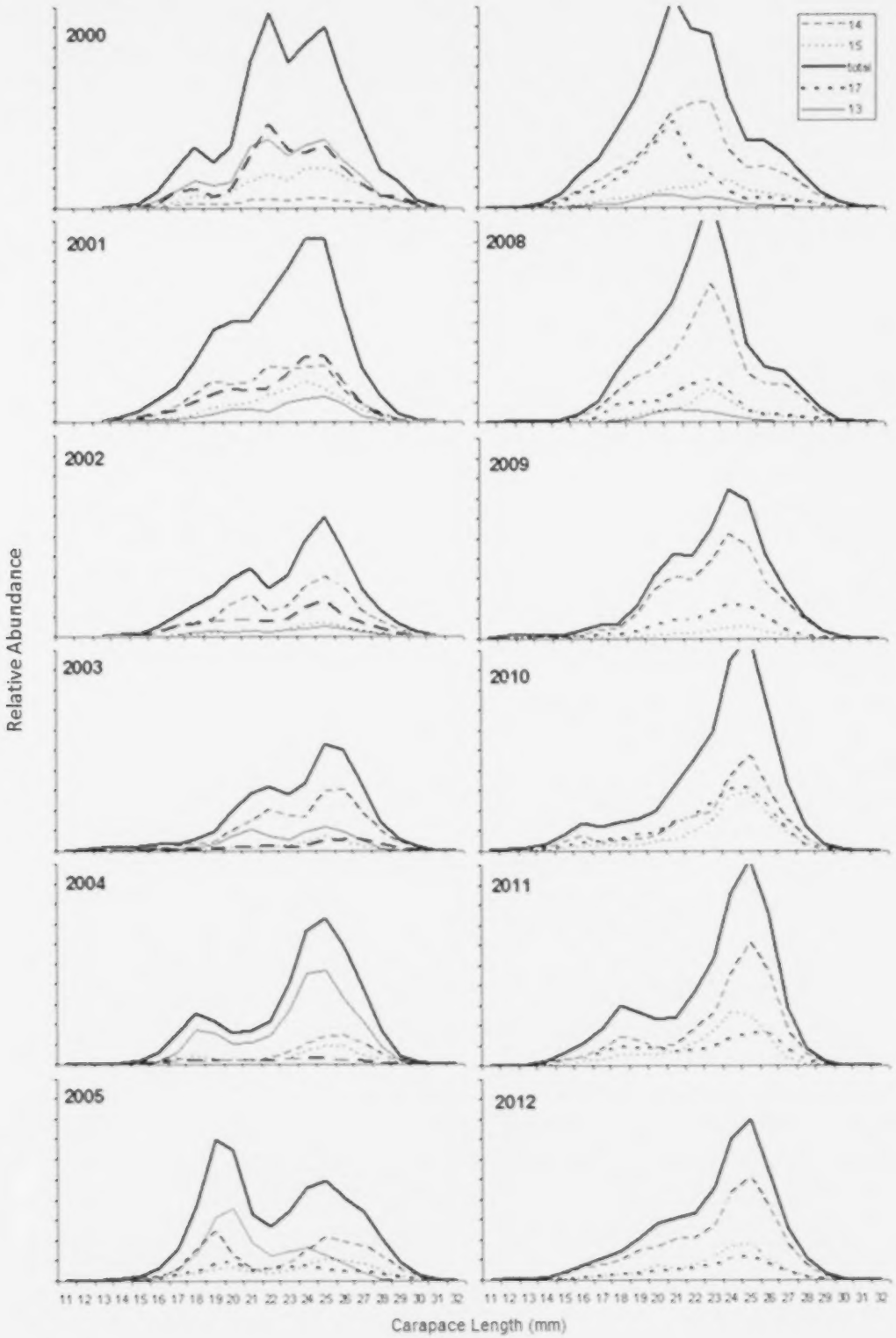


Figure 10. Catch at length from commercial sampling, 2000-2012.

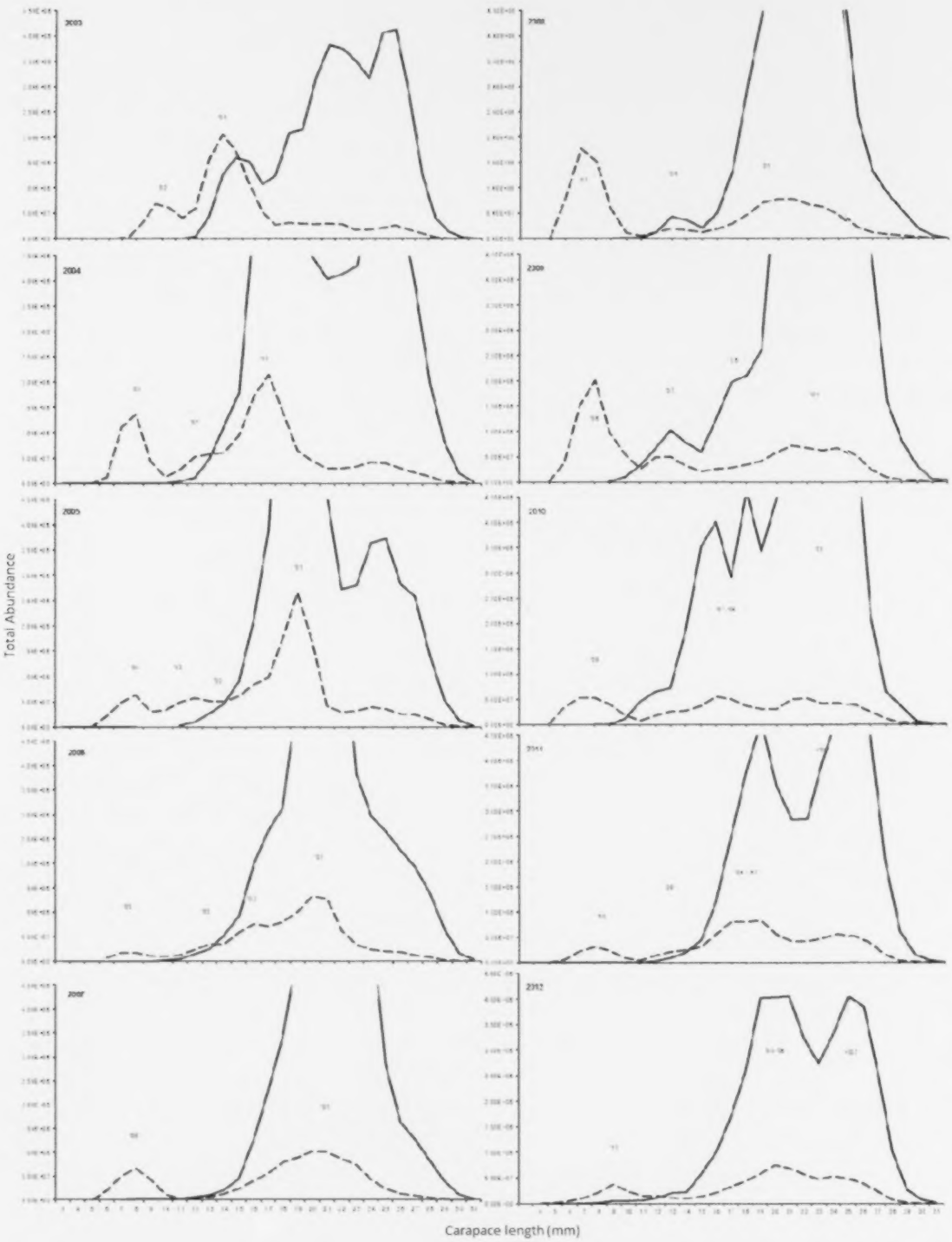


Figure 11. Population estimates from belly-bag (dashed line) and main trawl (solid line) catches for the 2003-2012 survey.

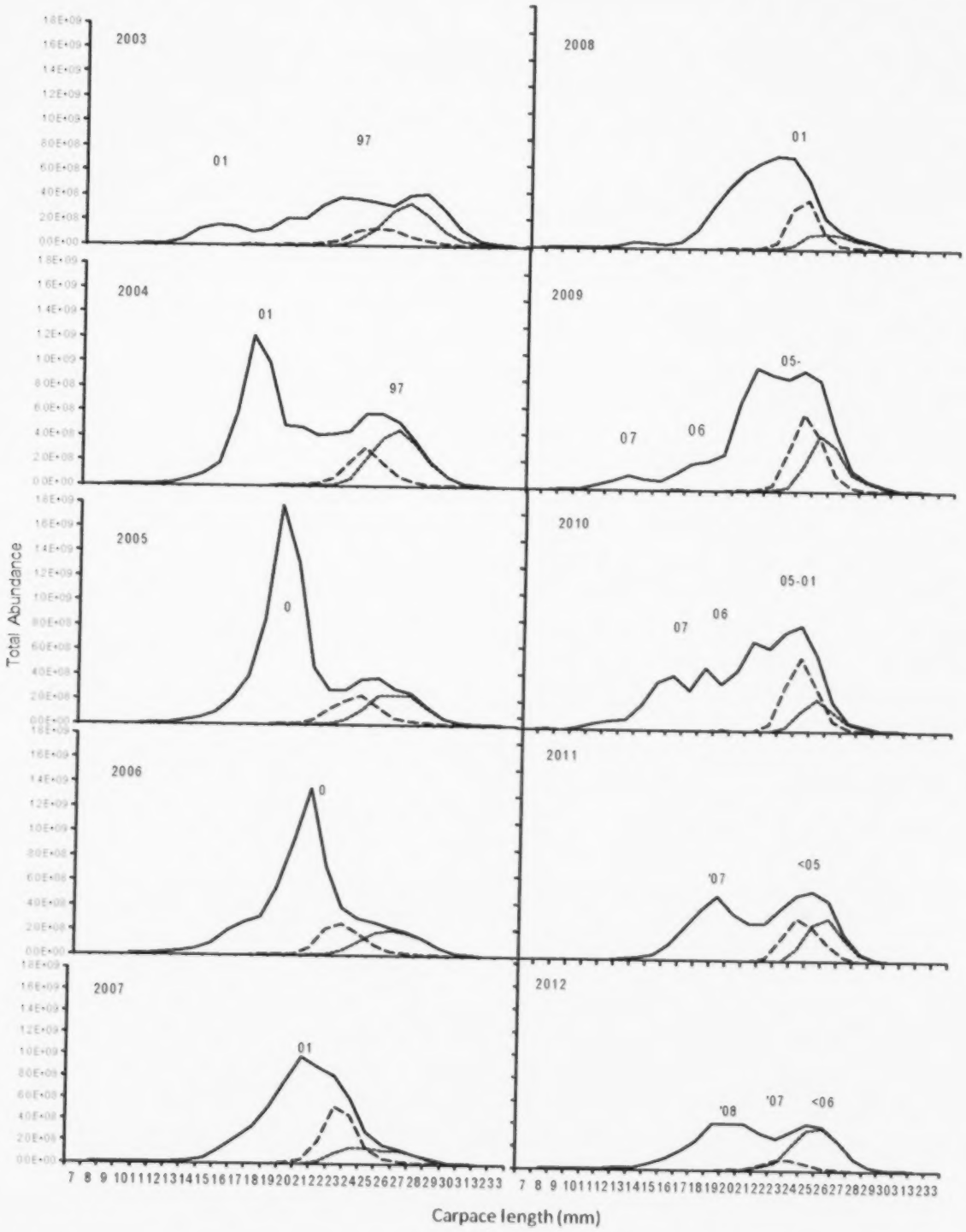


Figure 12. Population estimates at length from DFO-industry surveys 2003-2012 (solid line). The heavy dotted line in each figure represents transitional and primiparous shrimp, and the stippled line represents multiparous shrimp.

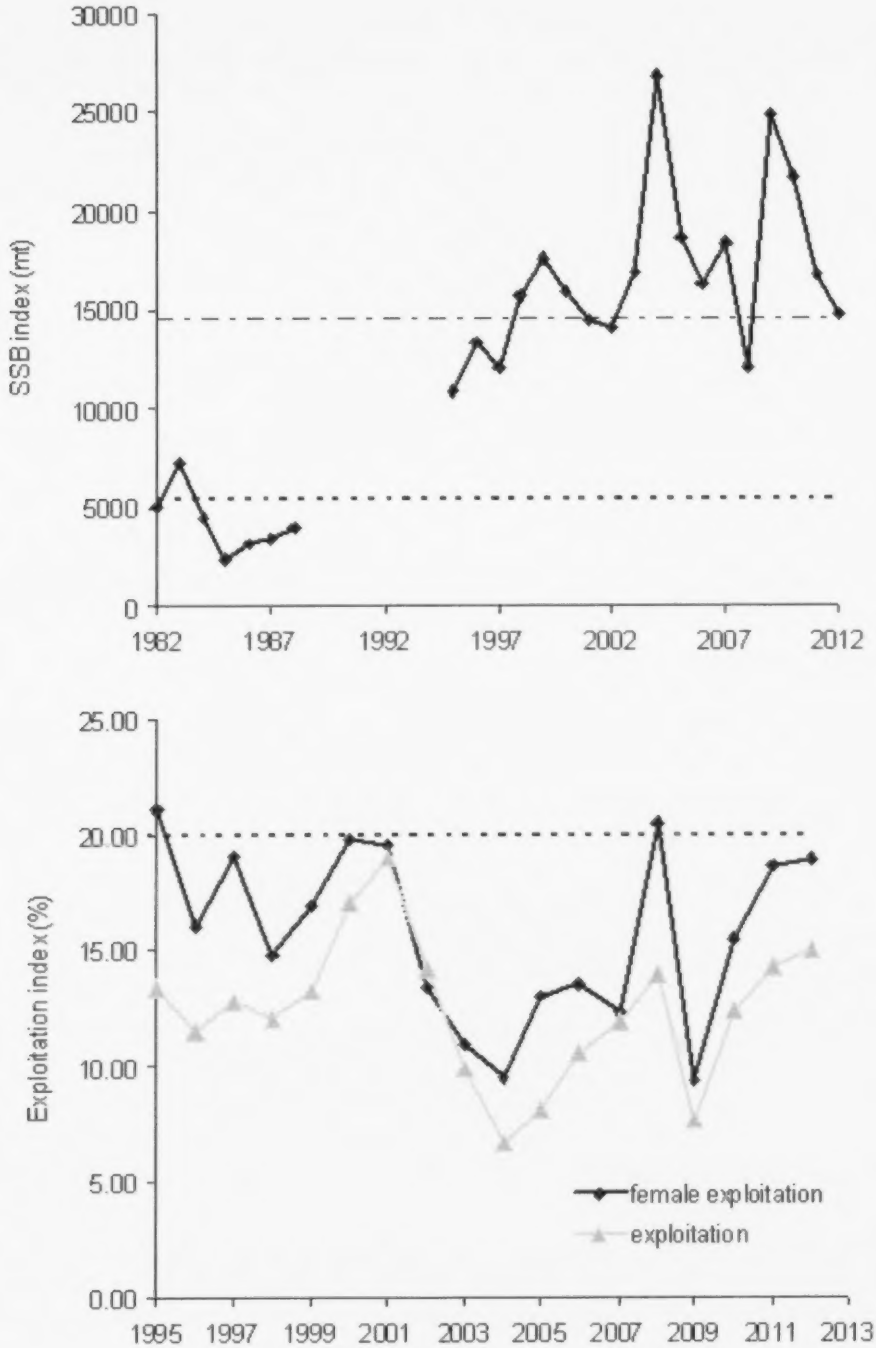


Figure 13. Changes in the SSB index (top) and the total and female exploitation indices (bottom) for the eastern Scotian Shelf shrimp population, from 1995-2012. The dashed line shows the LRP at 30% of the mean value during the 2000-2010 high-productivity period (top) and the LRP of 20% for the exploitation index (bottom).

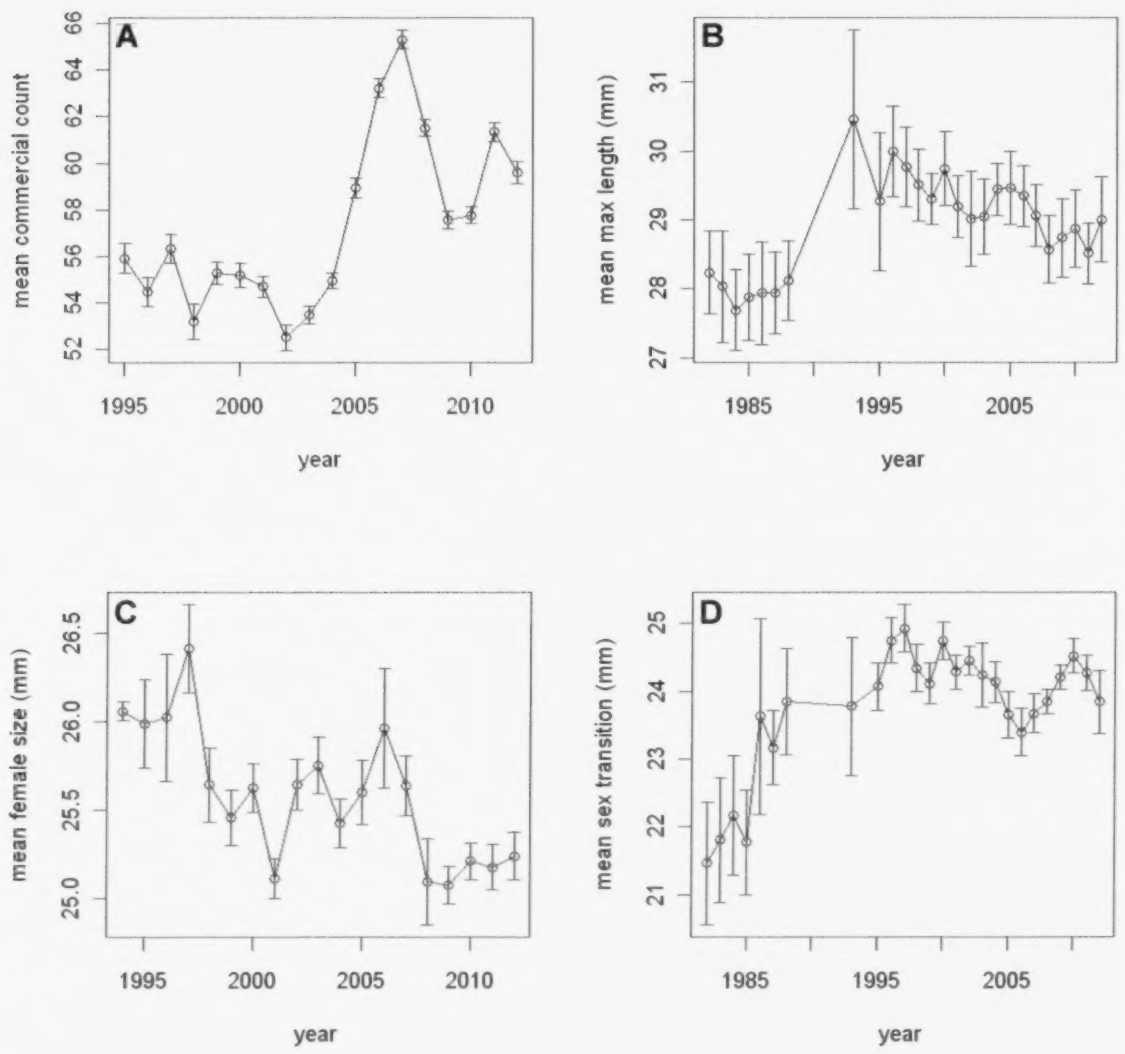


Figure 14. Averages for commercial count (A), maximum length (B), female size (C) and size at sex transition (D) for all SFAs combined for 1995-2012 with 95% confidence intervals.

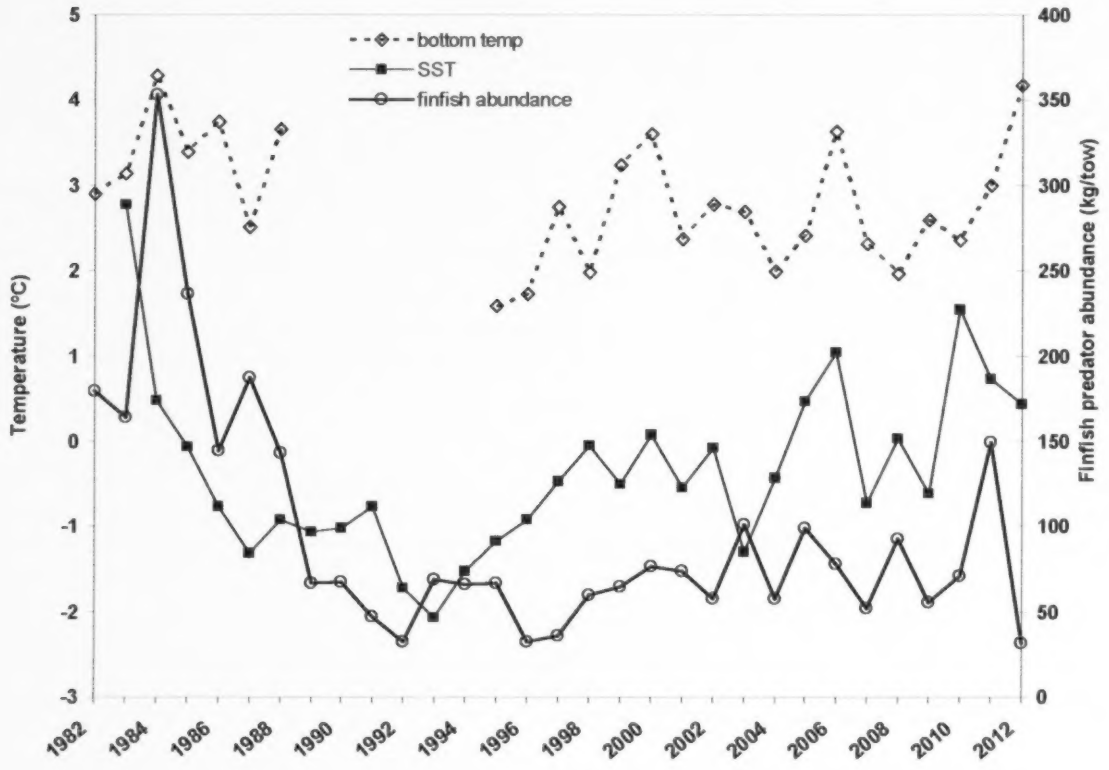


Figure 15. Bottom temperatures (°C) and finfish predator abundance (kg/tow) on the eastern Scotian Shelf shrimp grounds.

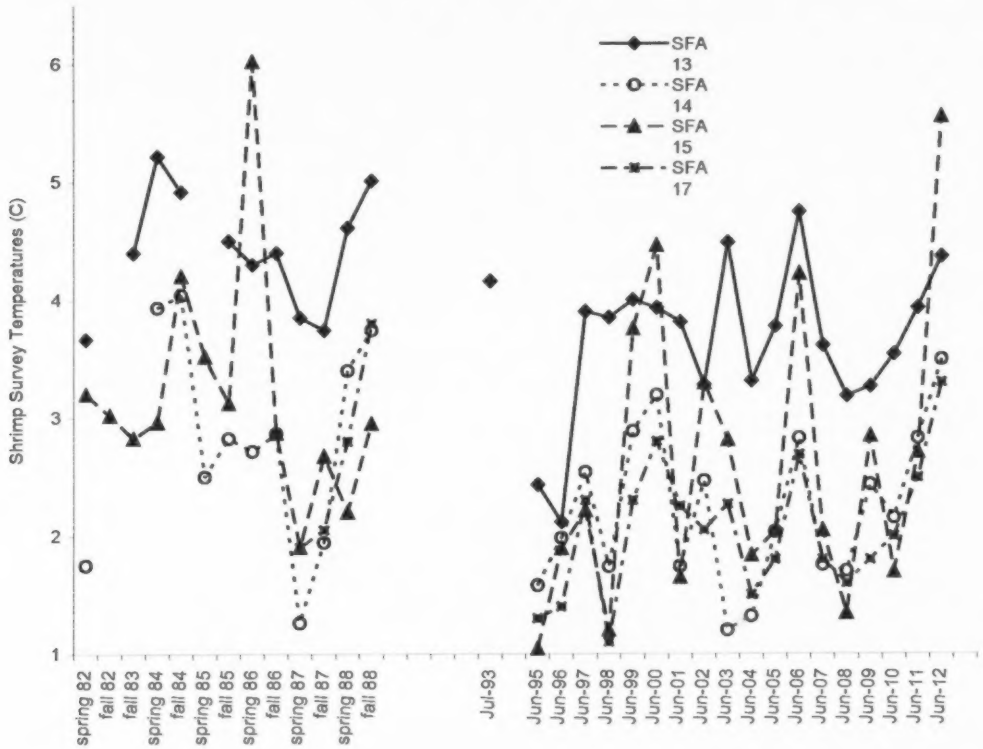


Figure 16. Mean bottom temperatures (°C) from shrimp surveys by SFA (13, 14, 15 and 17). Note that both spring and fall values were available from the earlier series (1982-1988), but only one survey (June) was conducted annually in the recent series.